PB-217 033

LAKE ERIE ENVIRONMENTAL SUMMARY, 1963-1964

Federal Water Pollution Control Administration
Chicago, Illinois

May 1968

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U S Department of Commerce
Springfield VA 22151

UNITED STATES
DEPARTMENT OF INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
GREAT LAKES REGION

MAY 1968

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CHAPTER 1

INTRODUCTION

The Federal Water Pollution Control Administration and its antecedent, the Division of Water Supply and Pollution Control of the U. S. Public Health Service, have gathered a great amount of data on the physical, chemical, and biological characteristics of Lake Erie. Various reports by those agencies and others have been based on the gathered data.

This report is an attempt to summarize the information gathered in the years 1963 through 1965. The purposes are (1) to provide a document for validating previous reports on the pollution problems in Lake Erie and (2) to provide a base for comparison with future lake surveillance data.

Adequate understanding of the significance of the reported data requires a knowledge of physical features and history of the basin, as summarized in the following description.

AREA DESCRIPTION

GENERAL

Lake Erie is centered at 42°15' North Latitude and 81°15' West Longitude, with its long axis oriented at about N70°E. The lake is approximately 240 miles long and more than 50 miles wide near the midpoint of its long axis. Figure 1 shows the Lake Erie basin as described in this report.

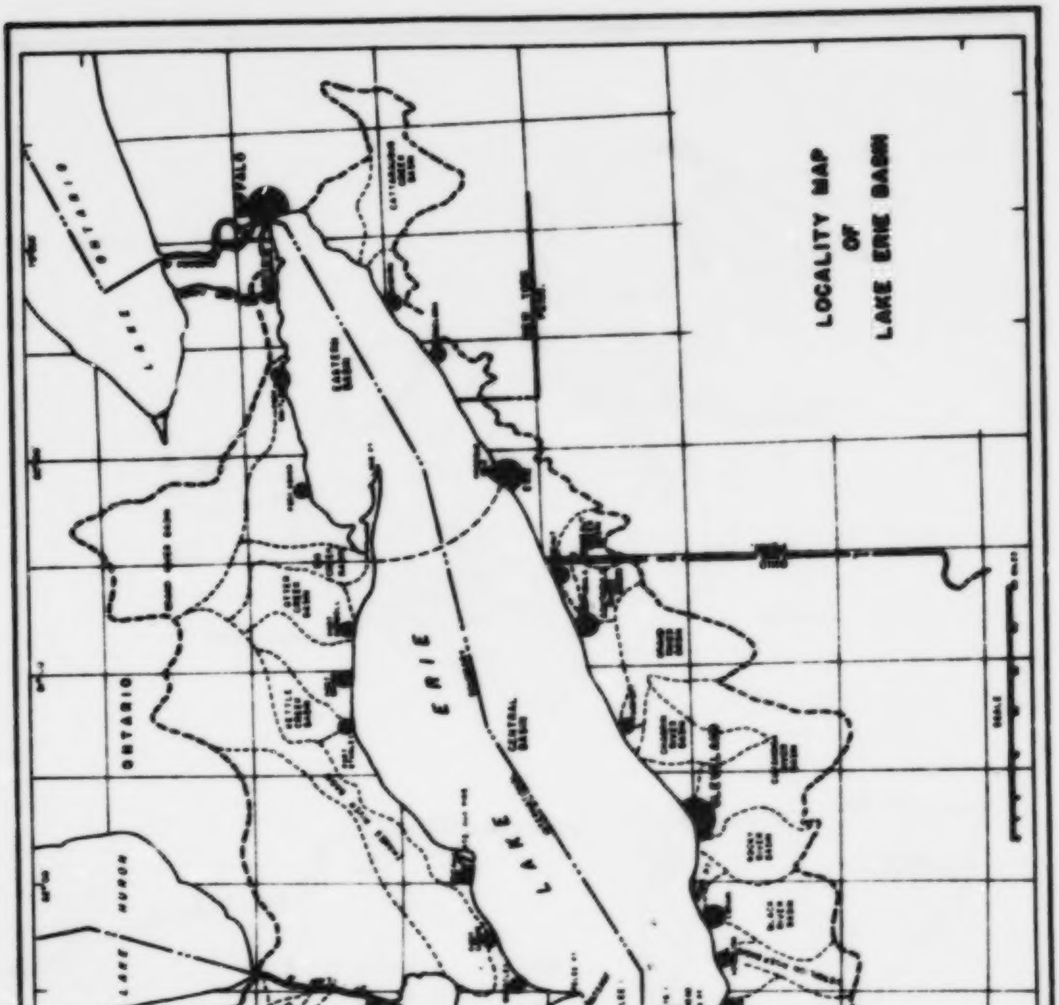
The area of the Lake Erie basin is about 32,500 square miles--about 40,000 square miles if the Lake St. Clair drainage area is included. Nearly one-third (9,940 square miles) of the Lake Erie basin is covered by the lake itself, a ratio which is approximated in each of the other Great Lakes basins. However, Lake Erie receives the drainage of the three lake basins above it, so that the total watershed supplying Lake Erie is in reality 260,000 square miles.

In terms of surface area, Lake Erie ranks fourth of the five Great Lakes. Only twelve freshwater lakes in the world are larger. The depth of Lake Erie, however, is remarkably shallow, averaging only 60 feet and reaching a maximum of 216 feet. Its total volume is 125 trillion gallons, the smallest of the Great Lakes (see Figure 2 and Table 1), storing only two percent of the total Great Lakes volume.

TABLE I

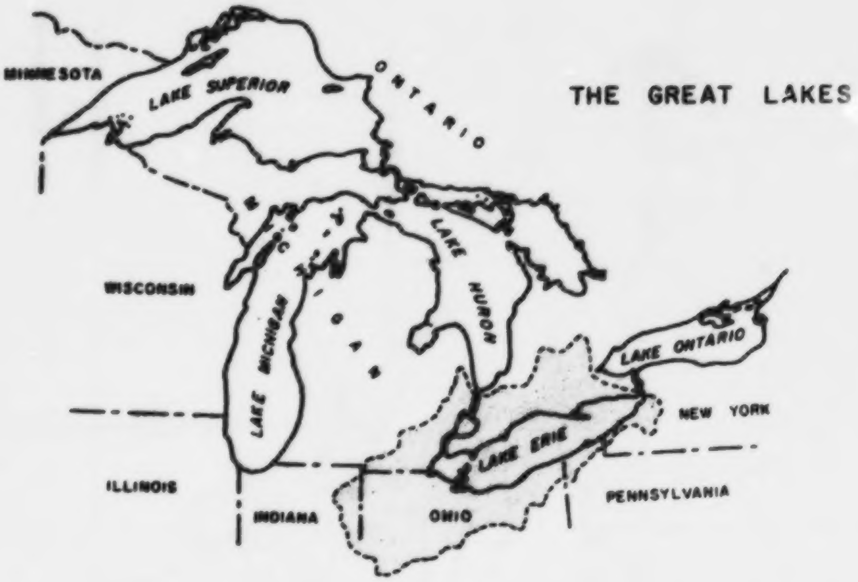
PHYSICAL FEATURES OF GREAT LAKES SYSTEM

Lake	Length (miles)	Breadth (miles)	Water Area (sq. miles) U.S.	Water Area (sq. miles) Canada	Total	Mean Depth (feet)	Drainage area (sq. miles)
Superior	350	160	20,700	11,200	31,900	487	80,000
Michigan	307	118	22,400	--	22,400	276	67,860
Huron	206	183	9,110	13,900	23,010	195	72,620
St. Clair	26	24	200	290	490	10	7,430
Erie	241	57	4,990	4,940	9,930	60	32,490
Ontario	193	53	3,600	3,920	7,520	283	34,800
Totals			61,000	34,250	95,250		

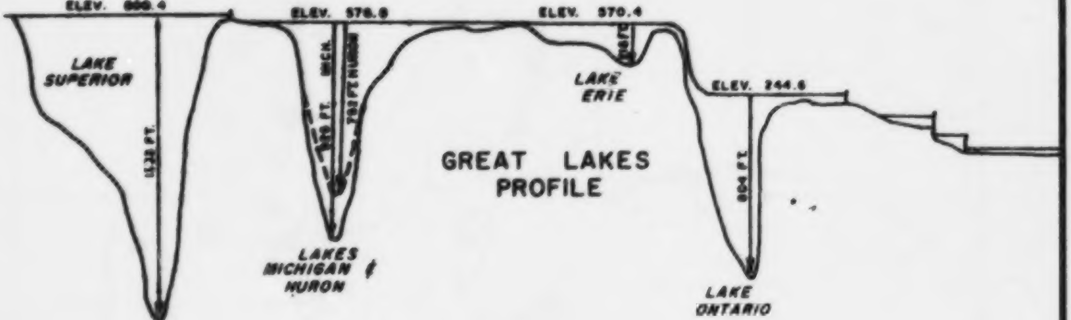

LAKE ONTARIO
BUFFALO
EASTERN BASIN
CATTARAUGUS CREEK BASIN
ONTARIO
LAKE ERIE
CENTRAL BASIN
CLEVELAND
ROCKY RIVER BASIN
BLACK RIVER BASIN
HURON RIVER BASIN
SANDUSKY RIVER BASIN
PORTAGE RIVER BASIN
MAUMEE RIVER BASIN
LAKE HURON
CLINTON RIVER BASIN
ROUGE RIVER BASIN
RAISIN RIVER BASIN
DETROIT
TOLEDO
WESTERN BASIN
SCALE

LOCALITY MAP OF LAKE ERIE BASIN

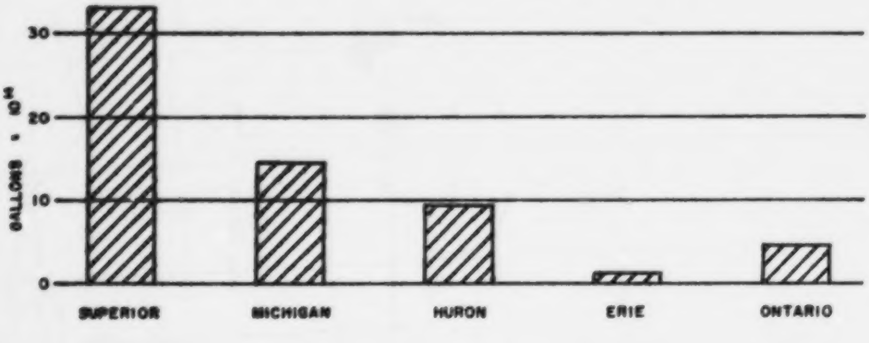
FIGURE 1


MINNESOTA
LAKE SUPERIOR
ONTARIO
WISCONSIN
MICHIGAN
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
NEW YORK
LAKE ERIE
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA

THE GREAT LAKES


ELEV. 600.4
ELEV. 576.8
ELEV. 570.4
ELEV. 244.6
LAKE SUPERIOR
1333 FT.
MICH.
923 FT.
750 FT. HURON
LAKES MICHIGAN & HURON
LAKE ERIE
804 FT.
LAKE ONTARIO

GREAT LAKES PROFILE



GREAT LAKES STORAGE

FIGURE 2

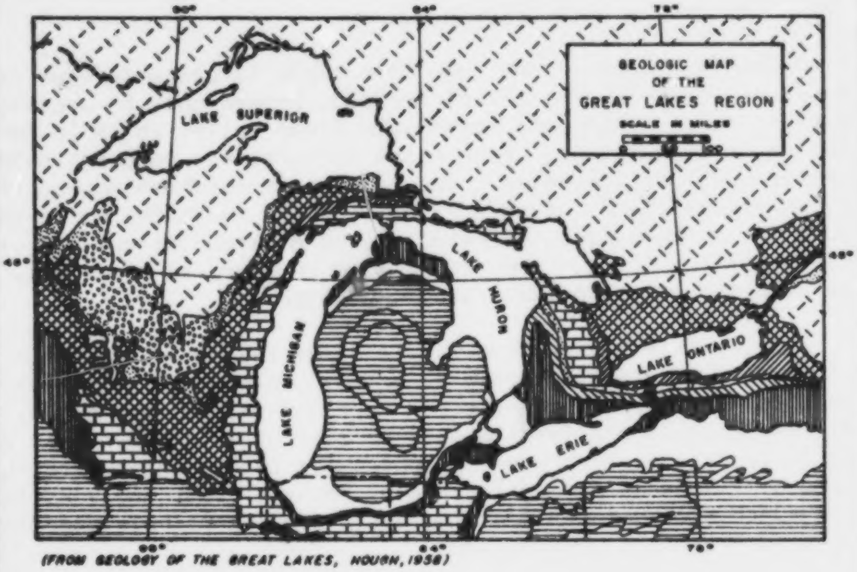
The water of Lake Erie lies entirely above that of Lake Ontario, into which it drains. Lake Erie owes its existence both to the Niagara bedrock sill, which acts as a dam, and to glacial scouring during the Ice Age. The form of Lake Erie reflects the bedrock structure of the area, Figure 3.

The landscape of the Lake Erie basin is characterized by thousands of square miles of flat terrain, broken only by occasional ancient beach ridges and relatively steep valley walls in many of the major tributaries. Even these features are subdued in the western part of the basin. The terrain is less monotonous from Cleveland eastward, along the south shore, where the basin reaches into the northwestern perimeter of the Appalachian uplands with their rolling hills. However, the basin there is relatively narrow between the lake and the drainage divide.

Soils in the extensive flatlands of the Lake Erie basin are characteristically dominated by poorly drained and relatively impervious clays, derived from old lake and glacial sediments, Figure 4. These soils are fertile and, because of this, have been artificially drained to a great extent. The uplands along the southeast edge of the basin are well-drained, rock-derived, and less fertile. Old beach ridges throughout the basin are extensively used for highways and farming.

Streams entering Lake Erie are generally low-gradient and winding but with steep-walled valleys. They carry large silt loads where they traverse easily eroded clay flatlands and smaller loads in the rocky hilly areas. Excluding the Detroit River input, only two streams, the Maumee River in Ohio and the Grand River in Ontario, supply significant quantities of water to the lake.

Lake Erie proper is unique among the Great Lakes in several of its natural characteristics, each of which has a direct bearing on its condition with respect to pollution. Lake Erie is by far the shallowest of the Great Lakes and the only one with its entire water mass above sea level. It has the smallest volume, 113 cubic miles, and its flow-through time of 920 days is the shortest. It is the most biologically productive and the most turbid. It has the flattest bottom; it is subject to the widest short-term fluctuations in water level (13 feet maximum); and its seasonal average surface levels are the most unpredictable. It is the only one of the Great Lakes with its long axis paralleling the prevailing wind direction and is subject to violent storms. Lake Erie is also the southernmost, warmest, (averaging 51°F) and the oldest (12,000 years) of the Great Lakes.


90°
84°
78°
48°
GEOLOGIC MAP
OF THE
GREAT LAKES REGION
SCALE IN MILES
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE

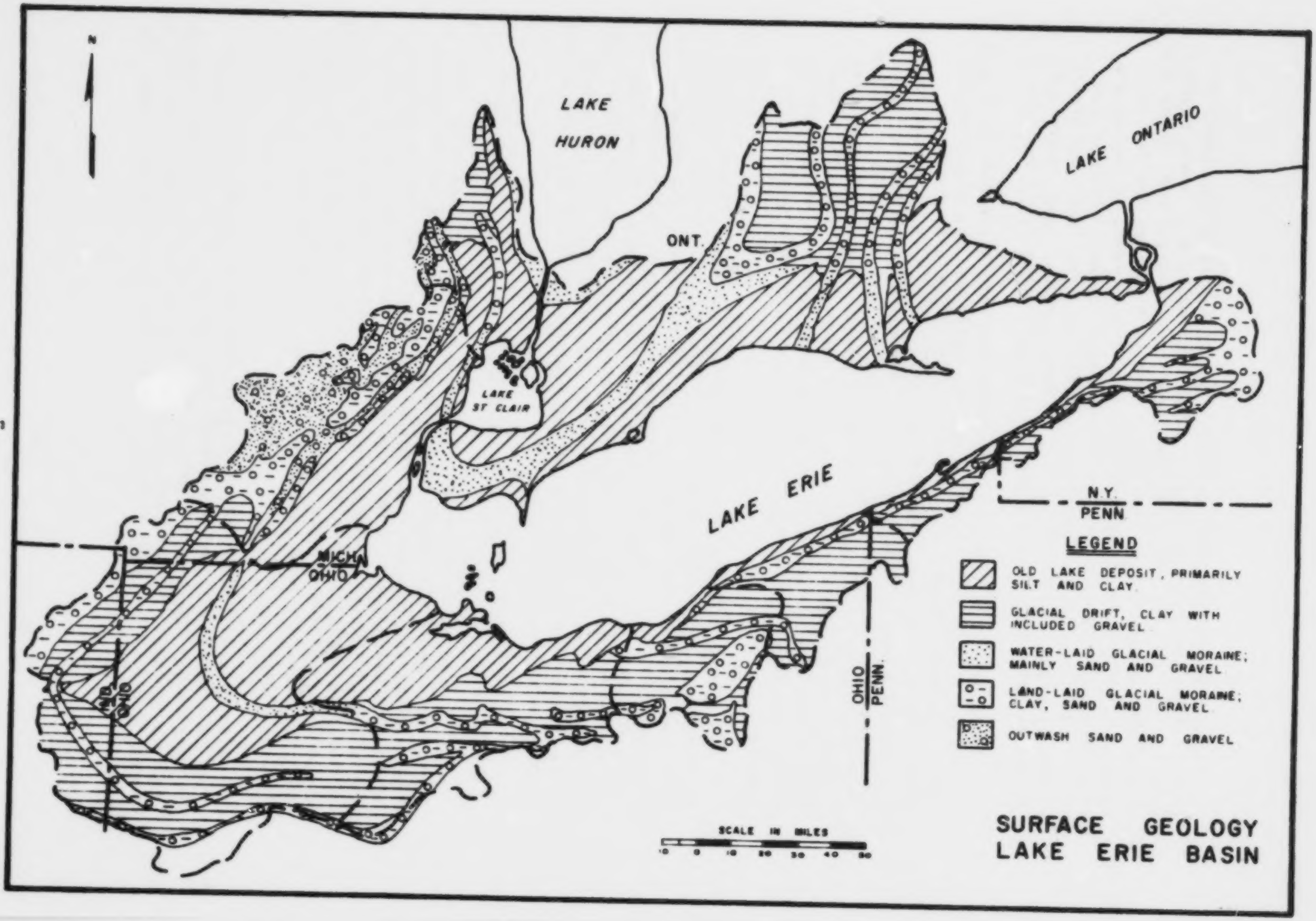
(FROM GEOLOGY OF THE GREAT LAKES, HOUGH, 1958)

LEGEND

- ▤ PENNSYLVANIAN AND MISSISSIPPIAN ROCKS, UNDIFFERENTIATED.
- ☐ UPPER DEVONIAN ROCKS, MAINLY SHALES: ANTRIM SHALE IN MICHIGAN.
- ■ LOWER DEVONIAN ROCKS, IN UNITED STATES: DEVONIAN UNDIFFERENTIATED IN CANADA.
- ▧ UPPER SILURIAN ROCKS, IN ONTARIO AND NEW YORK (MAINLY DOLOMITE)
- ▒ SILURIAN SALINA GROUP ROCKS IN NORTHERN MICHIGAN AND ONTARIO (INCLUDES SALT BEDS)
- ▦ MIDDLE SILURIAN NIAGARAN SERIES ROCKS IN NORTHERN MICHIGAN, ONTARIO, AND NEW YORK. SILURIAN ROCKS UNDIFFERENTIATED IN WISCONSIN, IOWA, ILLINOIS, INDIANA, AND OHIO.
- ■ LOWER SILURIAN ROCKS IN NORTHERN MICHIGAN, ONTARIO, AND NEW YORK.
- ▩ ORDOVICIAN ROCKS, UNDIFFERENTIATED.
- ░ CAMBRIAN ROCKS, UNDIFFERENTIATED.
- ▨ PRECAMBRIAN ROCKS, UNDIFFERENTIATED. (MAINLY METAMORPHIC AND IGNEOUS ROCKS)

BEDROCK GEOLOGY OF GREAT LAKES AREA

FIGURE 3


N
LAKE HURON
LAKE ONTARIO
ONT.
LAKE ST CLAIR
LAKE ERIE
MICH
OHIO
IND
OHIO
N.Y.
PENN
OHIO
PENN
LEGEND
OLD LAKE DEPOSIT, PRIMARILY SILT AND CLAY.
GLACIAL DRIFT, CLAY WITH INCLUDED GRAVEL.
WATER-LAID GLACIAL MORAINE; MAINLY SAND AND GRAVEL.
LAND-LAID GLACIAL MORAINE; CLAY, SAND AND GRAVEL.
OUTWASH SAND AND GRAVEL
SCALE IN MILES
10 0 10 20 30 40 50

SURFACE GEOLOGY
LAKE ERIE BASIN

FIGURE 4

Lake Erie's shores are characterized by easily eroded banks of glacial till and not much sand. Bluffs of limestone or shale bedrock exist in the islands area, between Vermilion and Cleveland, Ohio, and around the eastern end of the lake. Good sand beaches are few in number, but where developed, are built to the extreme. Examples are Long Point, Pointe aux Pins, and Point Pelee, Ontario; Cedar Point, Ohio; and Presque Isle, Pennsylvania. The till and lake clay bluffs recede by erosion at rates up to 5 or more feet per year, contributing an average of 16 million tons of sediment annually to the lake.

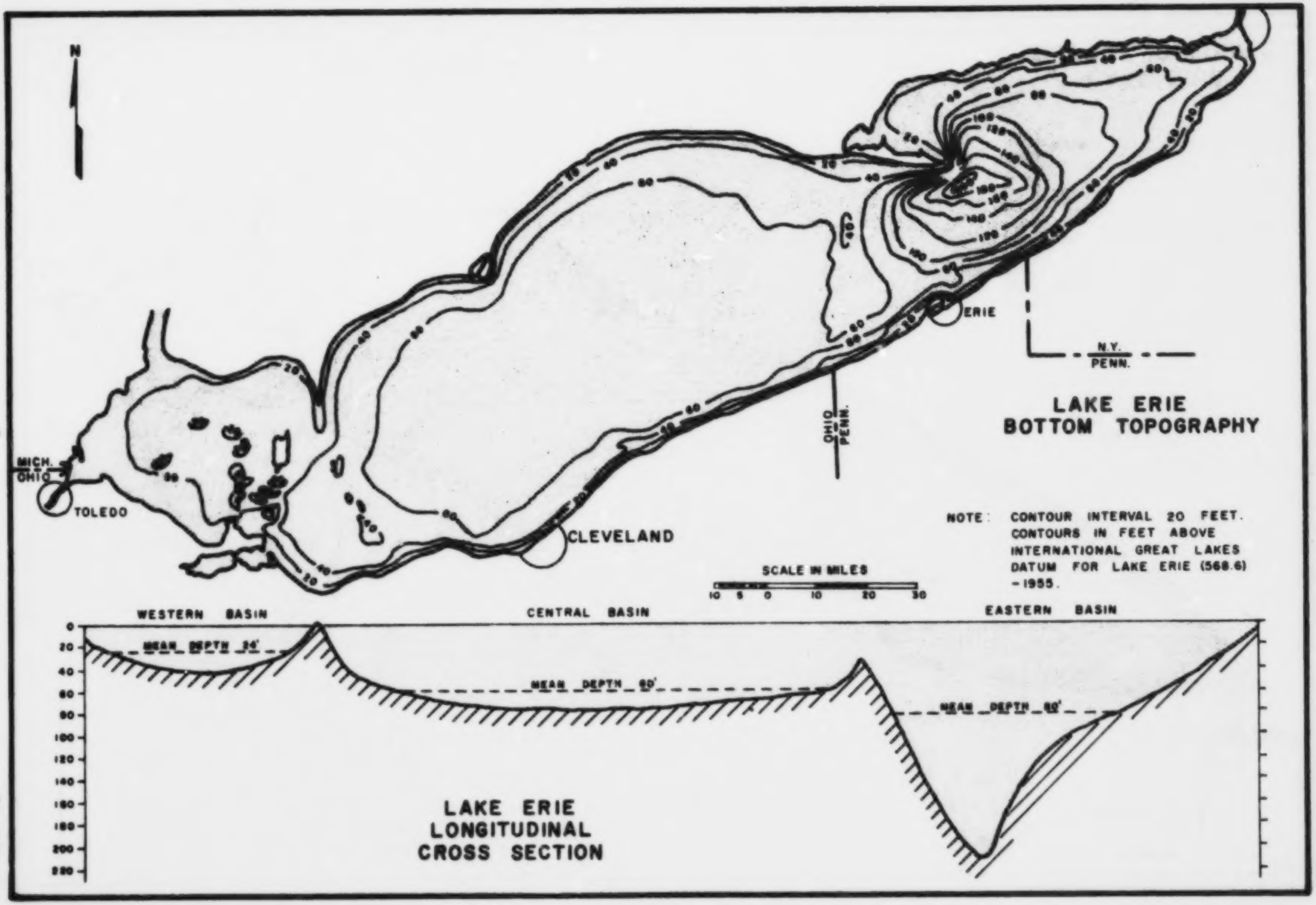
Topographically, Lake Erie is separated into three basins, Figure 5. The relatively small shallow western basin is separated from the large, somewhat deeper, flat-bottomed central basin by the rocky island chain. The deep, bowl-shaped eastern basin is separated from the central basin by a low, wide sand and gravel ridge near Erie, Pennsylvania. The western basin averages 24 feet deep with a maximum of 63 feet in South Passage; the central basin averages 60 feet with a maximum of 80 feet; the eastern basin averages 80 feet with a maximum of 216 feet. The areas of the western, central, and eastern basins are approximately 1,200, 6,300, and 2,400 square miles, respectively.

The bottom sediments of Lake Erie show patterns closely related to topography and relief, Figure 6. In general, the broad, remarkably flat areas of the western and central basins and the deeper, smoother part of the eastern basin have mud bottoms and are the recipients of nearly all of the sedimentation in Lake Erie. Ridges and shoreward-rising slopes are generally comprised of sand and gravel and are characterized by either erosion or the deposition of coarse sediments. Rock is exposed in the western basin and in strips along shores in the central and eastern basins.

GEOLOGY

It is generally believed that the antecedent of Lake Erie, prior to the Ice Age (Pleistocene Epoch), was a major stream valley essentially along the long axis of the present lake. The land topography, although showing slightly more relief, was probably not far different than that of today. The drainage or river system was controlled by differential bedrock resistance and large-scale rock structural features. Bedrock nearest the surface, as it is today, was comprised of shales and limestones and some sandstone, laid down, long before, in epicontinental seas.

The glacial history of the Great Lakes basin is described in detail by Hough (1958) and by Leverett and Taylor (1915). Glaciation by continental ice sheets began on the North American continent approximately one million years ago, representing the beginning of the Pleistocene Epoch of geologic history. Four great ice invasions, named the



LAKE ERIE
BOTTOM TOPOGRAPHY

NOTE: CONTOUR INTERVAL 20 FEET. CONTOURS IN FEET ABOVE INTERNATIONAL GREAT LAKES DATUM FOR LAKE ERIE (568.6) - 1955.

LAKE ERIE
LONGITUDINAL
CROSS SECTION

N
MICH.
OHIO
TOLEDO
CLEVELAND
ERIE
OHIO
PENN.
N.Y.
PENN.
20
40
60
80
100
120
140
160
180
200
SCALE IN MILES
10 5 0 10 20 30
WESTERN BASIN
CENTRAL BASIN
EASTERN BASIN
MEAN DEPTH 24'
MEAN DEPTH 60'
MEAN DEPTH 80'
0
20
40
60
80
100
120
140
160
180
200
220

FIGURE 5

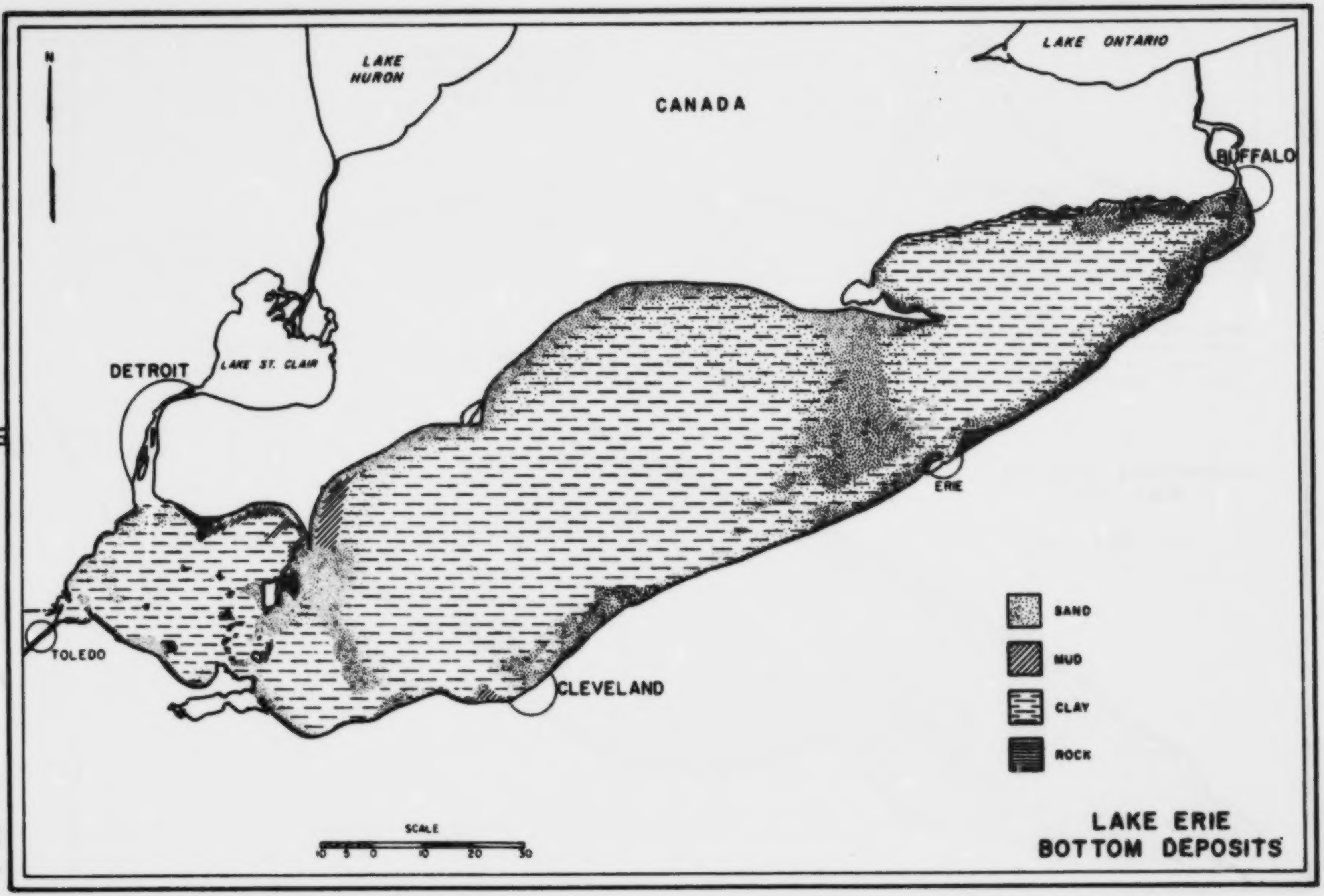

LAKE ERIE
BOTTOM DEPOSITS
SAND
MUD
CLAY
ROCK
LAKE ONTARIO
BUFFALO
ERIE
CANADA
CLEVELAND
LAKE HURON
LAKE ST. CLAIR
DETROIT
TOLEDO
N
SCALE
10 5 0 10 20 30

FIGURE 6

Nebraskan, Kansan, Illinoian, and Wisconsin, characterized this period. Apparently all of these ice sheets covered the Great Lakes region. However, each succeeding invasion obscured or obliterated most of the evidence for the preceding one. In the Lake Erie basin the features produced by Wisconsin glaciation are of the most concern. There are meager remnants of Illinoian glaciation and none of previous activity.

Apparently the Wisconsin ice sheet moved into the Lake Erie basin from the north and northeast about 25,000 years ago. It covered the entire lake area and nearly all of the drainage basin. In western Ohio the ice sheet moved south over flatlands to near the Ohio River while it was stopped by the Appalachian uplands in eastern Ohio, Pennsylvania, and New York.

Upon retreat of the ice sheet, a complex series of glacially-produced features were left behind, most of which resulted from temporary readvances and retreats of the ice front. The features are mainly ground and frontal moraines composed of crushed and reworked local bedrock. A lesser amount of the material is derived from bedrock to the north. This "erratic" material is conspicuous in many places as large crystalline boulders.

Lakes were generally not formed or were very transient features while the ice front was south of the Ohio River-Great Lakes drainage divide. A lake began its existence in the Erie basin when the ice front retreated from a position now represented by a frontal moraine called the Fort Wayne moraine, passing through Fort Wayne, Indiana. This moraine essentially lies along the shoreline of the first glacial lake stage (Lake Maumee) in the Lake Erie basin. The ice still covered what is now Lake Erie, its front lying along the Defiance moraine. The surface of Lake Maumee was at about 800 feet above sea level and the drainage was westward into the Wabash River in Indiana.

Following the Lake Maumee stage was a long series of stages, some draining westward and some eastward. The most significant of these stages are marked by well-developed beach ridges. They were Lake Maumee at 800 feet elevation, Lake Whittlesey at 740 feet, Lake Warren at 690 feet, and Lake Erie at 570 feet. All of these drained westward except for Lake Erie.

One of the most significant points to remember in regard to the history of the Great Lakes is that a lake has occupied the present Lake Erie basin for a much longer time than lakes have existed in the other basins.

The four stages mentioned above were the most important, but there were many intervening stages, not always successively downward, in the Erie basin, controlled by relatively minor retreats and advances of the ice front. Significant in this regard is the fact that ice occupied the eastern end of Lake Erie several times, possibly accounting for the present relative deepness of that part of the basin.

The water level in the Erie basin has not always been at its present level or higher. At least two stages have been considerably lower and did not receive drainage from the upper lakes. Both these stages have occurred in the last 11,000 years. The first one of importance was some 80 feet lower than the present lake. The lake then rose by ice damming and uplift to a level of 100 feet above the present lake. Ice retreat dropped the level again to 40 feet below the present lake. That stage was the immediate predecessor of Lake Erie as we know it today. The lake then began to rise (about 4,000 years ago) to its present level by uplift of the Niagara outlet; that rise continues today.

The differential resistance of the bedrock (see Figure 3) to glacial abrasion was responsible for a major part of Lake Erie's present form (Carman, 1946). The islands and headlands of western Lake Erie are remnants of resistant limestone and dolomite. Resistance also accounts in part for the shallow water depths in the west end of the lake. The broad flat central part of the lake lies along the strike of a broad band of uniformly resistant shales bounded on the south shore by similar shales capped by relatively resistant sandstones. The deeper eastern basin is also underlain by shales but has been subject to more abrasion and less, later sedimentation.

The Lake Erie basin lies mainly in the Central Lowlands physiographic province (Figure 7) near where it wedges out between the Appalachian Plateau and Laurentian Upland. The southeastern part of the drainage basin is in the Appalachian Plateau. The boundary between the Central Lowlands and the Appalachian Plateau in the Erie basin is a sharp rise of 200 to 300 feet in elevation called the Portage Escarpment. From Cleveland eastward the escarpment parallels the lake shore and lies generally less than five miles from it. At Cleveland the escarpment turns southward across Ohio.

The part of the Central Lowlands in the Lake Erie basin is called the Lake Plain and is for the most part the very flat former lake bottom. East of Cleveland it is narrow and lies between the Portage Escarpment and the present lake shore. West of Cleveland it widens quickly and in western Ohio it is more than 50 miles wide. It narrows again in Michigan to about 20 miles wide. In Canada it is 20 to 30 miles wide but is not so well defined because of the complexity of glacial features. The lake plain is characteristically low and comprised of poorly drained silt and clay with occasional sandy ridges formed as beaches and bars in older lakes.

The streams (except the Detroit River) entering Lake Erie originate either within or just outside the boundaries of the Lake Plain.

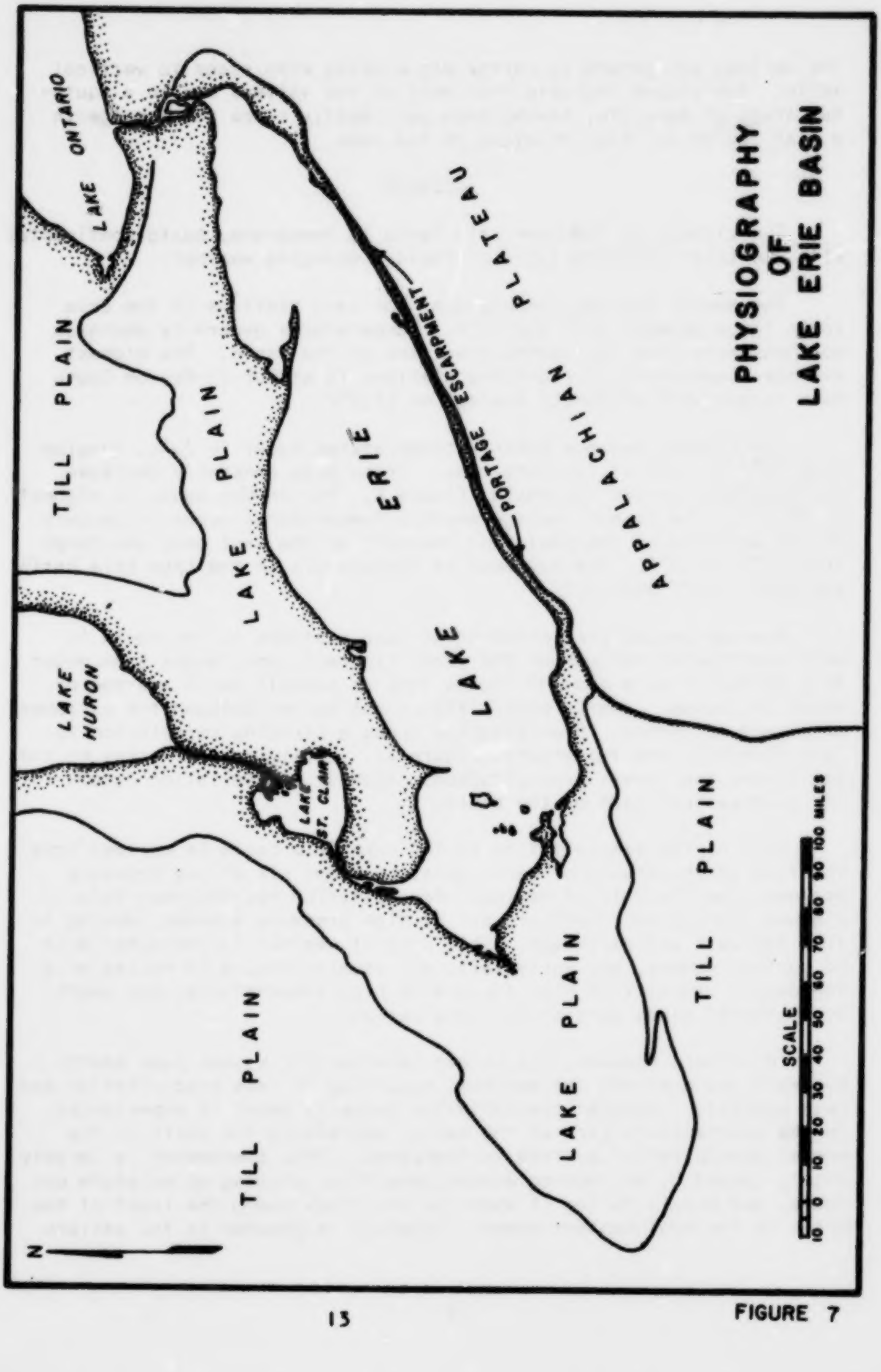

PHYSIOGRAPHY OF LAKE ERIE BASIN
LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
LAKE ERIE
TILL PLAIN
LAKE PLAIN
TILL PLAIN
LAKE PLAIN
TILL PLAIN
PORTAGE ESCARPMENT
APPALACHIAN PLATEAU
N
SCALE
10 0 10 20 30 40 50 60 70 80 90 100 MILES

FIGURE 7

The valleys are generally narrow and winding with steep to vertical walls. The shapes indicate that most of the valleys are in a youthful stage of maturity, having been cut rapidly since the Ice Age in a flat region but high relative to the lake.

CLIMATE

The climate of the Lake Erie basin is temperate, humid-continental with the chief characteristic of rapidly changing weather.

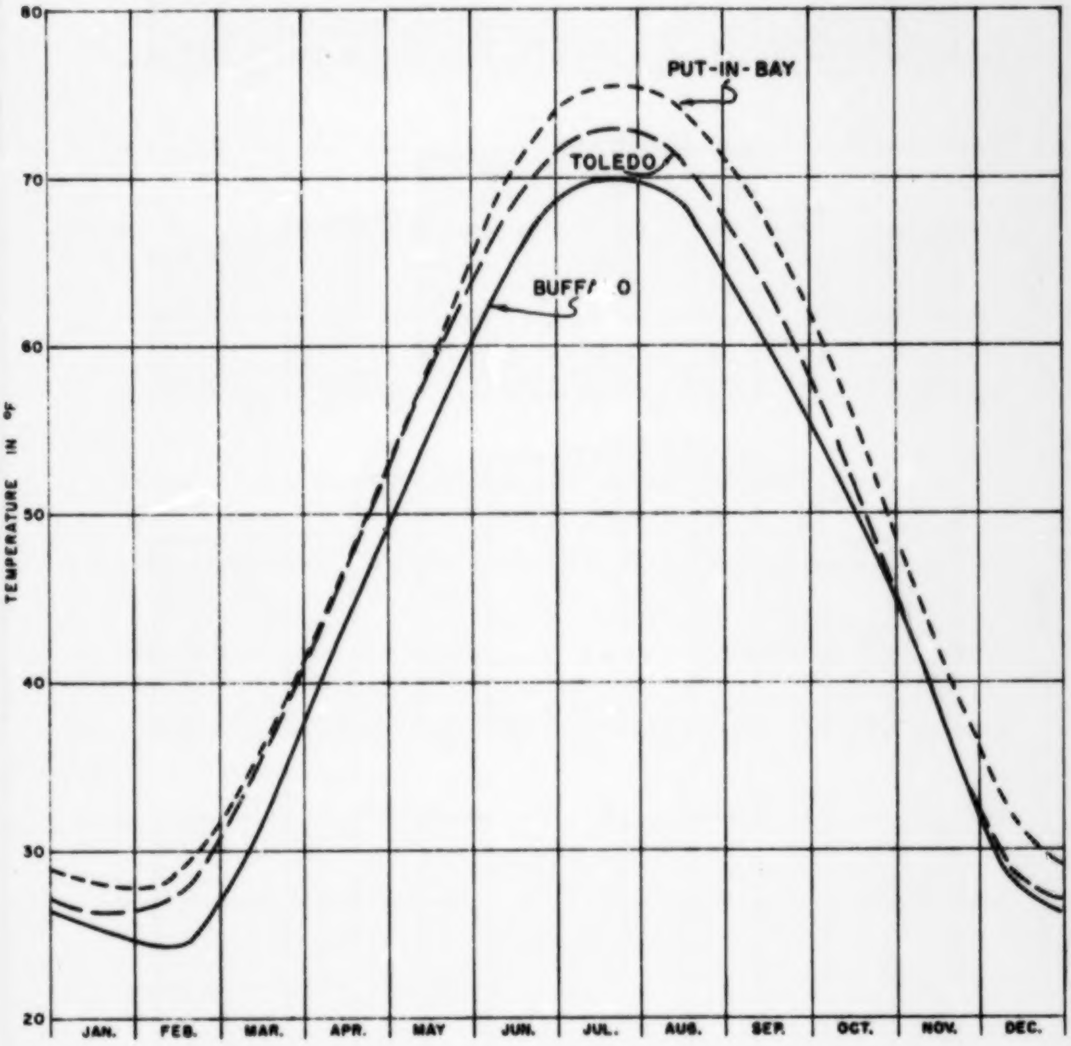
The annual average temperatures for land stations in the Erie basin range between 47°F and 50°F. Temperatures generally decrease northeastward from the southwestern end of the basin. The highest average temperature at recording stations is at Put-in-Bay on South Bass Island with an annual average of 51.2°F.

The highest average monthly temperatures occur in July, ranging from 70°F to 74°F at land stations. These also generally decrease northeastward across the basin, Figure 8. Put-in-Bay again is highest at 75.1°F. The lowest average monthly temperatures occur in January at the west end of the basin and February at the east end, and range from 24°F to 28°F. The extremes of temperature in the Lake Erie basin are about -20°F and 100°F.

Average annual precipitation at land stations in the basin is well-distributed throughout the year, Figure 9, and ranges from about 30.5 inches to more than 40 inches with an overall basin average of about 34 inches. Yearly precipitation has varied between the extremes of 24 and 43 inches. Precipitation shows a striking correlation to land elevation and topography, Figure 10. Low-lying flat areas of the basin have the lowest precipitation. Highest precipitation occurs in the southeastern part of the basin.

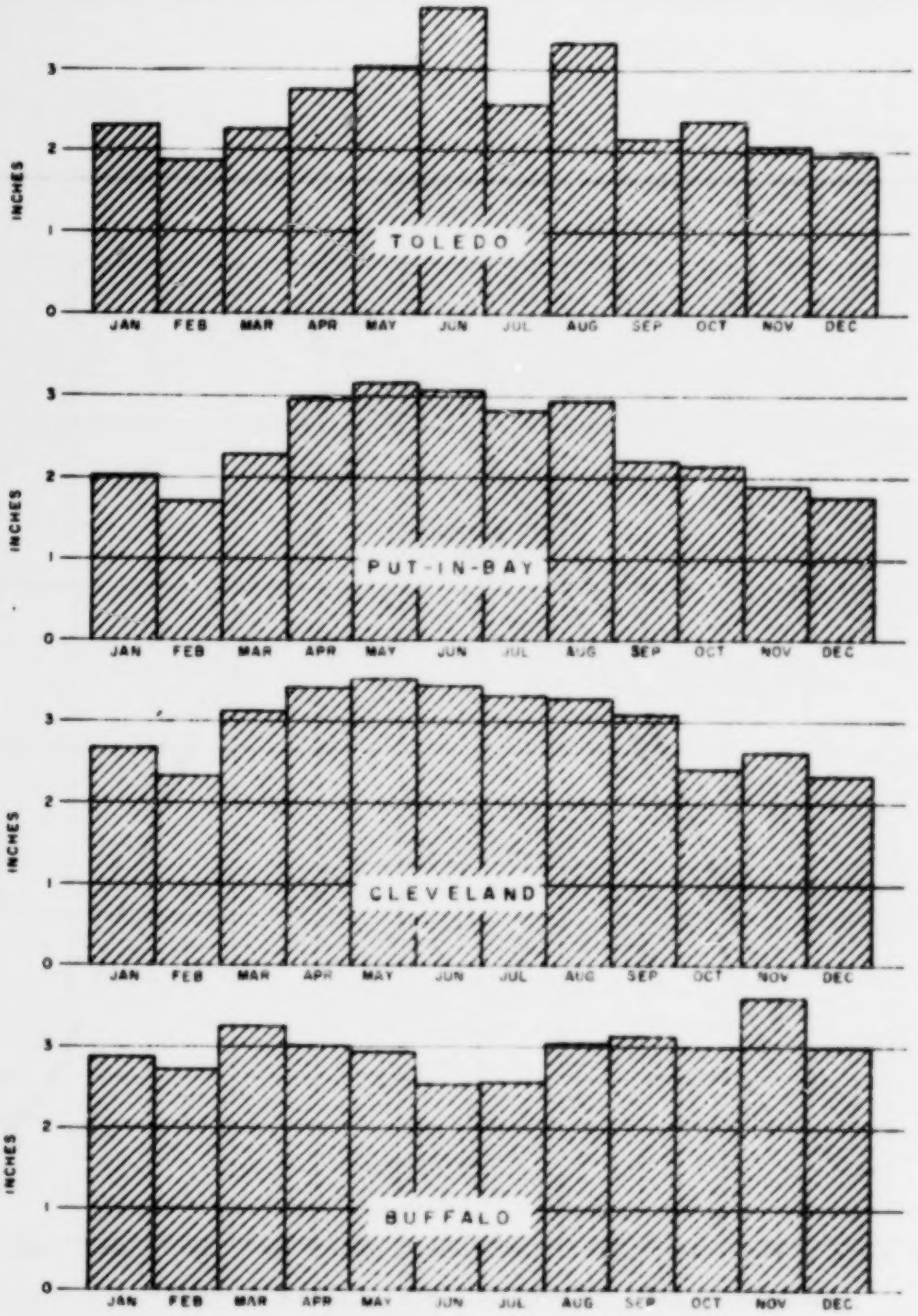
Most of the precipitation in the Lake Erie basin is derived from the flow northeastward of warm, moisture-laden air of low pressure systems from the Gulf of Mexico. Precipitation results when this clashes with colder, northern air of high pressure systems, moving in from the west and northwest. This kind of weather is characteristic of spring, summer, and early fall, and usually occurs in cycles of a few days. Humidity is high along with high temperatures, and south to southwest winds persist for long periods.

In winter, however, the colder Canadian air masses push southeastward and dominate the weather, resulting in less precipitation and less humidity. Heavier precipitation (usually snow) is experienced in the southeastern part of the basin, explaining the shift in the annual precipitation pattern in that area. This phenomenon is largely local, caused by air moving across Lake Erie, picking up moisture enroute, and precipitating it when the air rises along the front of the hills on the southeastern shore. Snowfall is greater in the eastern



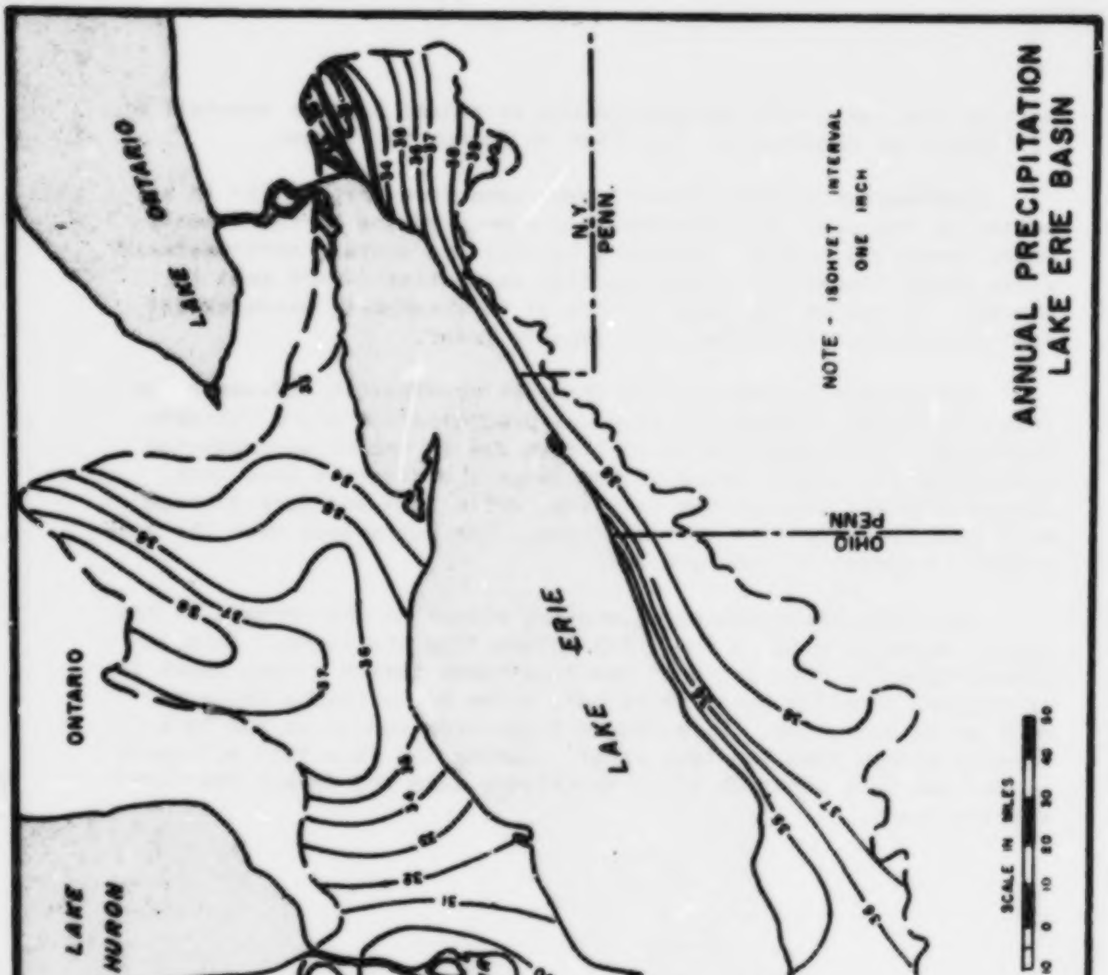
ANNUAL AIR TEMPERATURE CURVES FOR
TOLEDO, PUT-IN-BAY AND BUFFALO

FIGURE 8



AVERAGE MONTHLY PRECIPITATION AT LAND STATIONS
LAKE ERIE BASIN

FIGURE 9


LAKE ONTARIO
ONTARIO
LAKE HURON
LAKE ERIE
LAKE ST. CLAIR
N.Y.
PENN.
OHIO
PENN.
MICH.
OHIO
IND
OHIO
NOTE - ISOHYET INTERVAL ONE INCH
SCALE IN MILES
10 0 10 20 30 40 50
N

ANNUAL PRECIPITATION
LAKE ERIE BASIN

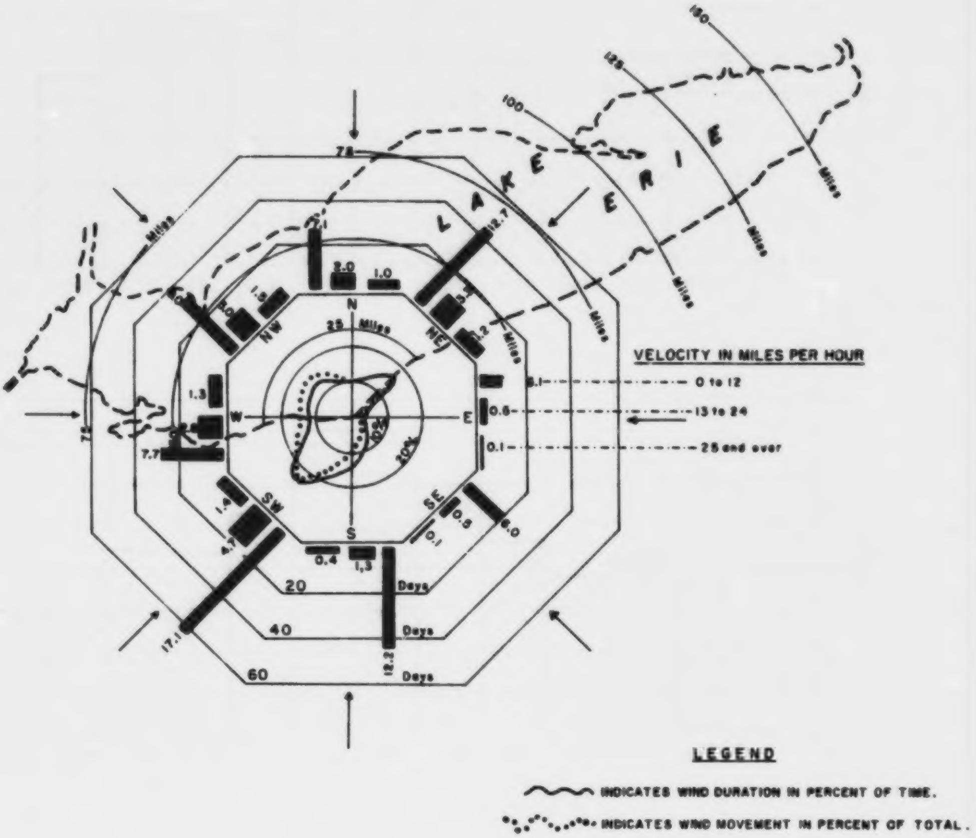
FIGURE 10

part of the basin with Buffalo having an annual average snowfall of 72 inches, as compared to less than 36 inches for Toledo.

Southwesterly winds prevail over Lake Erie (Figure 11) in all months of the year, a characteristic common to the northern hemisphere temperate region. However, in fall and winter, northwesterly winds occur frequently, reaching high velocities (40-50 mph) in storms. In spring the same is true of northeasterly winds except that velocities (30-40 mph) are usually lower.

The percent of possible sunshine is greatest in midsummer and least in winter, Figure 12, although precipitation might indicate otherwise. Less sunshine in winter is due to the cloud-producing effects of the lake. December and January ordinarily have less than 40 percent of possible sunshine, while June and July average more than 70 percent at most stations. The percentage over the lake proper in summer is even greater.

Lake Erie has a marked moderating effect on the climate of the basin, especially for a few miles inland from the shore. This is demonstrated by the length of the frost-free season - near shore it is greater than 200 days, while only a few miles inland it is as much as 30 days less. This longer frost-free season is due to a warming effect from the lake water. During the late fall and early winter the lake water is still relatively warm and delays the first killing frost.



NOTES:

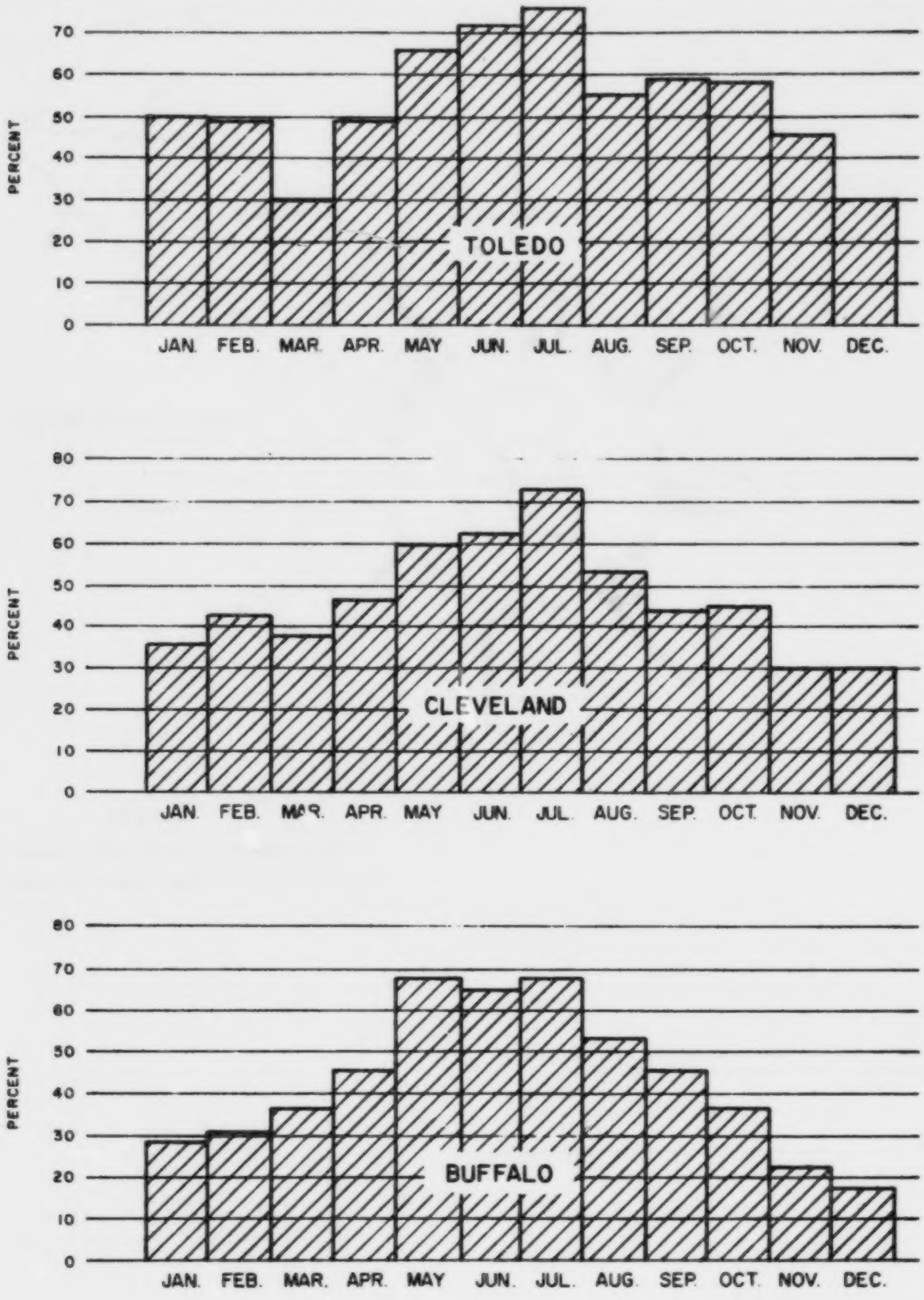
Figures at the end of bars indicate average yearly percentage of occurrence of wind in the direction and velocity shown.

Length of bar denotes duration in average days per year.

Wind data from logs of the U. S. Coast Guard, Cleveland, Ohio.

WIND DIAGRAM FOR CLEVELAND, OHIO

FIGURE 11



MONTHLY PERCENT OF POSSIBLE SUNSHINE 1965

FIGURE 12

CHAPTER 2

LAKE ERIE PHYSICAL CHARACTERISTICS

LAKE BOTTOM

Each of the three basins of Lake Erie contain unique physical features. Because of this, each basin will be described separately in some detail. Much of the description is taken from U. S. Lake Survey and Ohio Division of Geological Survey publications.

WESTERN BASIN

The western basin of Lake Erie is that part of the lake west of a line from Point Pelee through Kelleys Island to Marblehead, Ohio (Figure 1). Its long orientation is west-northwest, at an angle to the main east-northeast orientation of Lake Erie. The basin averages 24.5 feet in depth and covers an area of approximately 1,200 square miles. On its western and southern sides the bottom slopes gently from shore out to the 24-foot depth, five to ten miles offshore. On the north side of the basin the nearshore slope is steeper, the 24-foot depth being only one-half to two miles offshore (Figure 5). Beyond the 24-foot depth the bottom is very flat, reaching a maximum depth of only about 35 feet west of the Bass Islands. The flat bottom is generally mud, interrupted locally by small reefs and islands of rock, such as Niagara Reef, West Sister, and Middle Sister Islands (Figure 1).

The inter-island bottom, also mud, has considerably more relief, but much of it, too, is very flat. Depths are generally in the same range as those west of the islands. Within the more restricted channels, depths are considerably greater, due to current scour. The deepest of these are south of South Bass Island at 63 feet and north of Kelleys Island at 52 feet.

Reefs of bedrock are common around the islands. They generally have rough surfaces and steep slopes and rise to near or above lake level. Most of the rock exposures lie in two bands, one from Marblehead through Pelee Island, and the other from Catawba through the Bass Islands. Bedrock under the basin is fairly rough and in places is 80 feet or more beneath the lake bottom (Hartley, 1961). These depressions are filled with lake sediments.

Hard clay bottom is found in a narrow strip along the south shore and in a broader band near the northeastern shore of the western basin (Verber, 1957).

Sand and gravel are not abundant in western Lake Erie. Most of that which exists is found on beaches along the mainland shores, in a relatively large area off Locust Point, Ohio, across the mouth of Maumee Bay, and in the northern half of the eastern island chain (Figure 6).

Beach, bank, and nearshore bottom erosion is prevalent and in many places is a very serious problem especially in the Toledo area.

The shore banks around the western basin are mainly clay. Their height is less than 10 feet above lake level on the south shore. Dikes and swampsand are common. On the north shore the banks rise to 30 feet or more above the lake. Rock bluffs, up to 30 feet high, are found on the islands and the Catawba and Marblehead peninsulas.

CENTRAL BASIN

The central basin of Lake Erie extends from the islands eastward to the sand and gravel bar crossing the lake between Erie, Pennsylvania and Long Point, Ontario (Figures 1 and 6). The top of the bar is 40 to 50 feet below water level. The central basin has an area of about 6,300 square miles, an average depth of 60 feet, and a maximum depth of 80 feet. Approximately 75 percent of the central basin is between 60 and 80 feet deep.

The bottom of central Lake Erie is extremely flat over most of its area (Figure 5). The only relief features of any consequence are the shoreward-rising slopes of sand, gravel, and rock, and a low wide bar extending south-southeastward from Point Pelee, Ontario to near Lorain, Ohio. This bar is two to six miles wide and rises 15 to 20 feet above the general lake bottom. It separates a small, triangle-shaped, flat-bottomed basin with 40 to 50-foot depths from the main part of the central basin to the east. This small basin and the main basin have mud bottoms and are connected by a broad channel near the Ohio shore.

The mud, which covers more than two-thirds of the central Lake Erie bottom is generally dark gray in color and contains very little coarse material. In mid-lake it is similar in physical appearance for several feet downward from the surface (Hartley, 1961).

Sand and gravel are found on the bottom in a strip of varying width along the north and south shores of the basin. It reaches its greatest width of five miles or more between Cleveland and Fairport, Ohio.

Limestone and dolomite bedrock are found on the bottom at the extreme western end of the basin. Shale is exposed as a narrow strip discontinuously from Vermilion eastward along and very near the south shore. Otherwise bedrock does not reach the lake bottom surface in the central basin. At some places it is known to be more than 100 feet under the lake bottom.

Natural beaches are generally narrow to nonexistent along the south shore of central Lake Erie and along most of the north shore. The Cedar Point spit on the south shore and the spits at Pelee Point and Pointe Aux Pins on the north shore are exceptions. Harbor structures, such as those at Huron, Fairport, Ashtabula, and Conneaut on the south shore have created exceptional artificial beaches but have caused shore erosion problems on the down-drift sides (Hartley, 1964).

The north and south shores of the central basin are generally characterized by eroding banks of glacial till and lake-deposited silt and clay. On the south shore the banks rise in height from less than 30 feet near the west end to more than 70 feet at the east end of the basin. On the north shore they rise similarly to more than 100 feet at the east end. Rock bluffs are limited to shore stretches between Vermilion and Cleveland, Ohio. Rapid erosion of the shore banks has contributed a great amount of sediment to the central basin.

Rivers and streams emptying into the central basin are small and ordinarily provide an insignificant amount to the lake's water supply. In the past, however, they have contributed a very large amount to lake sediments.

The water of the central basin of Lake Erie is generally less turbid than that of the western basin because the basin is larger and deeper, and streams do not carry great loads of sediment. The western end of Lake Erie acts as a settling basin for most of the water supply to the central basin.

EASTERN BASIN

The eastern basin is that part of Lake Erie lying east of the bar between Erie, Pennsylvania and Long Point, Ontario (Figure 1 and Figure 5). It has an area of approximately 2,400 square miles and an average depth of about 80 feet. It is by far the deepest part of Lake Erie with a maximum depth of 216 feet (U. S. Lake Survey Chart No. 3).

The bottom of the eastern basin is relatively smooth but not flat like the western and central basins. Most of the bottom is mud (Figure 6) and is generally lighter-colored and more compact than that in the other two basins.

The eastern basin is bounded on the west and south and around the east end by relatively steep slopes on sand and gravel. Rock is exposed in a strip along both the north and south shores. As in most of

Lake Erie the beaches are generally narrow or absent with two notable exceptions. Presque Isle, Pennsylvania and the massive spit at Long Point, Ontario, are large natural accumulations of sand, together accounting for a large part of the beach sand in Lake Erie. Both of these spits have enclosed rather large shallow bays.

Rocky bluffs are found along most of the shore of the eastern basin with shale on the south shore and limestone on the north shore.

Rivers and streams entering the eastern basin are unimportant to the water supply of the lake even though the Grand River in Ontario supplies more than 2,000 cfs. The streams have been relatively small contributors of sediments.

The water in the eastern basin is clear compared to the remainder of Lake Erie. The shores are very resistant to erosion, sediment-laden streams are virtually nonexistent, and the water is much deeper, thereby minimizing wave agitation of bottom sediments. Also the central basin is a settling basin for nearly all of the eastern basin's water supply.

LAKE WATER

TRIBUTARY SUPPLY

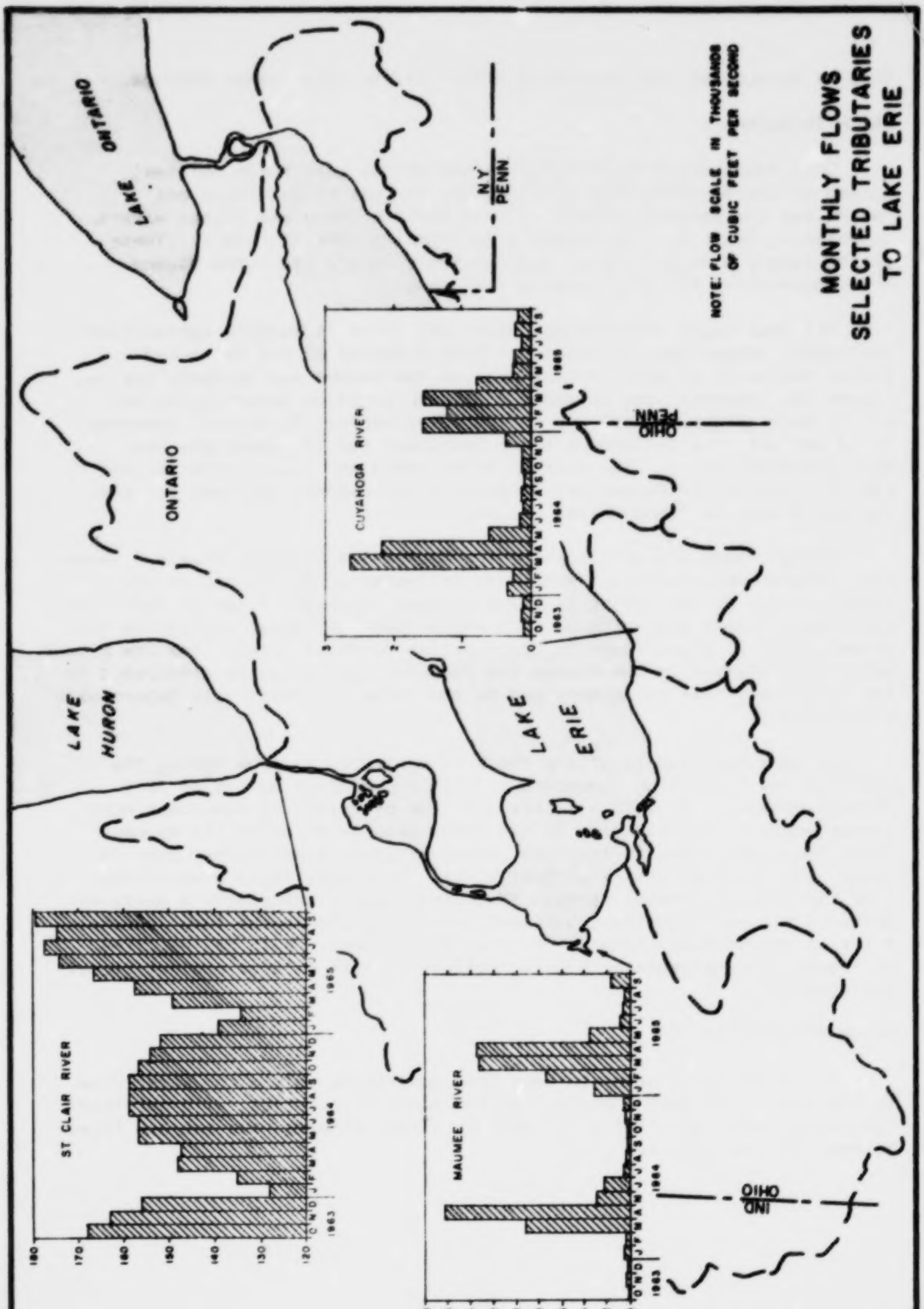
LAKE HURON OUTFLOW

Lake Erie receives 80 percent of its water supply from upper lake drainage. The large volume and high quality of this inflow have a great dilutional effect on Lake Erie, and any significant decrease in either the volume or quality could be disastrous.

The Lake Huron outflow is the only source of water to Lake Erie which is not controlled by precipitation over the Erie basin, being controlled instead by precipitation in the basins of Lakes Superior, Michigan, and Huron. Diversion out of Lake Michigan at Chicago, diversion into Lake Superior, and flow regulation from Lake Superior affect to a minor degree the Lake Huron discharge.

According to U. S. Lake Survey measurements, the Lake Huron outflow has averaged 187,450 cfs between 1860 and the present. The monthly averages have ranged from a high of 242,000 cfs in June 1896 to a low of 99,000 cfs in February 1942. Lowest flows ordinarily occur in February (average 159,000 cfs) and the highest in July or August (average 199,000 cfs), Figure 13. Other tributary runoff to Lake Erie is generally at a minimum during periods of high Lake Huron outflow.

Though the variation in flow volume from Lake Huron is great, it is still the most uniform of the tributary drainages to Lake Erie.


LAKE ONTARIO
ONTARIO
LAKE HURON
LAKE ERIE
NY / PENN
OHIO / PENN
IND / OHIO
NOTE: FLOW SCALE IN THOUSANDS OF CUBIC FEET PER SECOND
ST CLAIR RIVER
180
170
160
150
140
130
120
O N D J F M A M J J A S O N D J F M A M J J A S
1963
1964
1965
MAUMEE RIVER
18
16
14
12
10
8
6
4
2
0
CUYAHOGA RIVER
3
2
1
0

MONTHLY FLOWS
SELECTED TRIBUTARIES
TO LAKE ERIE

FIGURE 13

This is because of the regulating effect of the upper lakes storage.

MAJOR TRIBUTARIES

Only four Lake Erie tributaries beside the Lake Huron outflow, exceed an average discharge of 1,000 cfs to Lake Erie. These are the Maumee and Sandusky Rivers in Ohio and the Grand and Thames Rivers in Ontario, Table 2. The Thames discharges to Lake St. Clair. These rivers supply a total flow of approximately 10,000 cfs - the Maumee River accounting for about one-half of this.

All four major tributaries drain land which is largely agricultural and rather intensively cultivated. Precipitation on the Grand and Thames basins is slightly higher than on the Maumee and Sandusky basins, Figure 10. However, the percentage of precipitation appearing as unoff is considerably greater in the Canadian basins, 36 percent compared to 28 percent, the difference being accounted for in topography and soil characteristics. The average water yield per square mile is just over 0.7 cfs in the Maumee and Sandusky River basins, and over 0.9 cfs for the Grand and Thames River basins.

Drough flows are very low for the Maumee and Sandusky Rivers. Seven-day, 10-year recurrence low flows are estimated at 86 cfs and 14 cfs, respectively, at the mouths of these streams. Drought flows of the Grand and Thames Rivers appear to be much higher per unit area, indicating that ground water is significant in contributing to those flows. The low ground water contribution in the Maumee and Sandusky basins can be attributed to the relatively flat topography and to the dense and relatively impermeable clay soils.

In many upstream locations there is virtually no flow during the critical low flow, high temperature, high evaporation months of July through October. Flow is also low and time of travel is long near most stream mouths. For example; in the lower several miles of the Maumee River the flow volume is low, the cross-sectional area of the river is large, and the gradient is virtually nil. This results in a very long time for water to travel through the Toledo area - frequently a month or more. A similar situation, but less severe, exists in the lower several miles of the Sandusky River. At other localities in both basins, time of travel is lengthened by pooling effects of both natural and artificial features.

MINOR TRIBUTARIES

All other tributaries to Lake Erie contribute only minor water flow to the lake. The more important of the minor tributaries, with pertinent hydrologic data, are listed in Table 2. These streams have average flows between 200 and 900 cfs.

TABLE 2

RUNOFF STATISTICS FOR TRIBUTARIES OF THE LAKE ERIE BASIN

Stream	Drainage Area (mi.^{2})	Period of Record (years)	Max. Flow (cfs)	Min. Flow (cfs)	Average Flow (cfs)	Average Yield (cfs/mi.^{2})	7-Day Low Flow, 10 yr. Recurrence (cfs/mi.^{2})	7-Day Low Flow, 10 yr. Recurrence (cfs at mouth)*	Runoff Precip. %
St. Clair River (Lake Huron outflow)		106			187,450				
Clinton River	740	31	21,200	---	470	.635	.052	24	28
Rouge River	467	35	13,000	1.8	235	.503	.033	7.8	22
Huron River (Mich.)	890	19	5,840	4.0	556	.625	.044	24	27
Raisin River	1,125	28	12,900	2.0	714	.635	.027	19.3	28
Maumee River	6,586	40	94,000	20.0	4,794	.728	.013	86	29
Portage River	587	33	11,500	0.3	403	.687	.001	0.6	28
Sandusky River	1,421	39	28,000	4.4	1,021	.719	.010	14.0	28
Huron River (Ohio)	403	15	25,800	2.2	296	.732	---	5.1±	28
Vermilion River	272	15	20,500	0.0	228	.840	---	0.6±	33
Black River	467	21	24,000	0.0	302	.647	---	0.5±	29
Rocky River	294	34	21,400	0.2	273	.929	.004	1.0	35
Cuyahoga River	813	34	24,800	14.0	850	1.045	---	112	39
Chagrin River	267	36	28,000	3.0	333	1.247	.051	4.0	46
Grand River (Ohio)	712	40	21,100	0.0	784	1.101	.003	2.2	40
Ashtabula River	137	34	11,600	0.0	169	1.234	.000	0.0	45
Conneaut Creek	191	28	17,000	0.2	257	1.346	.006	1.2	49
Cattaraugus Creek	436	25	35,900	6.0	705	1.617	.129	55	58
Buffalo River	565	25	35,000	2.8	784	1.388			55
Grand River (Ont.)	2,614	24	47,800	65.0	2,405	.920			36
Big Creek	281	7	3,060	54.0	256	.911			35
Otter Creek	316	13	4,140	10.8	312	.987			37
Kettle Creek	200±	-	2,400±	7±	185±	.902			34
Thames River	2,000±	7	38,500±	58	1,840	.902			36

* All except Cuyahoga River and Cattaraugus Creek do not include all flows from STPs below or above gaging station.

The Portage and Raisin Rivers are similar in most characteristics to the Sandusky and Maumee Rivers except for much lower average flows. The minor tributaries in Ontario are also similar to the Grand and Thames Rivers.

The Huron River in Ohio is similar to the Sandusky in flow characteristics except that it has a higher base flow per unit area and its basin is partly in higher land, approaching the hilly section of the lake watershed. Ground water appears to be more important as a part of this stream supply.

From the Huron (Ohio) basin eastward along the Ohio shore, precipitation generally increases (Figure 10) and a greater share of the precipitation reaches the lake as runoff (Table 2). Drought flows are, however, widely variable and again reflect the ability of ground water to support stream flow. In addition, these streams have higher gradients and runoff is much faster. The upstream reaches of most of these streams may be completely dry during much of the summer-fall low flow period.

All of the streams along the south shore become sluggish in the lower few miles, a characteristic accentuated by the harbor enlargement of stream cross-section. The time-of-travel in the dredged channels is often a week or more. The 7-day low flow volume for the Cuyahoga River (Table 2) is relatively high, due to impoundments and large waste water discharges to the river, rather than ground water supply.

The important minor tributaries in Michigan are the Clinton, Rouge, Huron, and Raisin Rivers. The Clinton discharges into Lake St. Clair, the Rouge into the Detroit River, and the Huron and Raisin directly into Lake Erie. All are highly polluted streams, passing through the urbanized and industrialized area of southeast Michigan. They all drain relatively flat land, and not only is precipitation the lowest, but the proportion of runoff to precipitation is also the lowest in the Lake Erie basin. However, their drought flows are higher than average per unit area, indicating that perhaps there is significant release of ground water or surface storage. The Clinton and Huron are fed by several small natural lakes, but the Rouge and Raisin are not. There are several low-head dams near the mouth of the Raisin River.

The lower few miles of Michigan tributaries are dredged, sluggish, and lake-affected. Time of travel is long and especially long in summer and fall. The streams are similar to the south shore minor tributaries mentioned above in having long time-of-travel characteristics.

GROUND WATER

Ground water in the soil and rocks surrounding Lake Erie varies widely in both quantity and quality, Figures 14 and 15. Quantity alone is not a good indicator of supply capacity because of differences in retention characteristics of the soil. For example, glacial clays may contain much water, with the water table very near the surface, but their low permeability makes them a poor source of water supply.

Although characteristics vary, the basin as a whole is a rather poor producer of ground water. Tills, lake clays, and shales which are prevalent over much of the basin are not good aquifers - producers of water. Where they do produce significant quantities, it is not uncommon for the water to have a high sulfur content. Locally high quantities of water may be available where deep sandy soils occur as the result of beach-building or glacial outwash, or in old valleys filled with gravelly soils. Porous limestones are also locally good aquifers as are sandstones, but all of these sources, except for sandstones, may contain sulfur.

LAKE WATER BALANCE

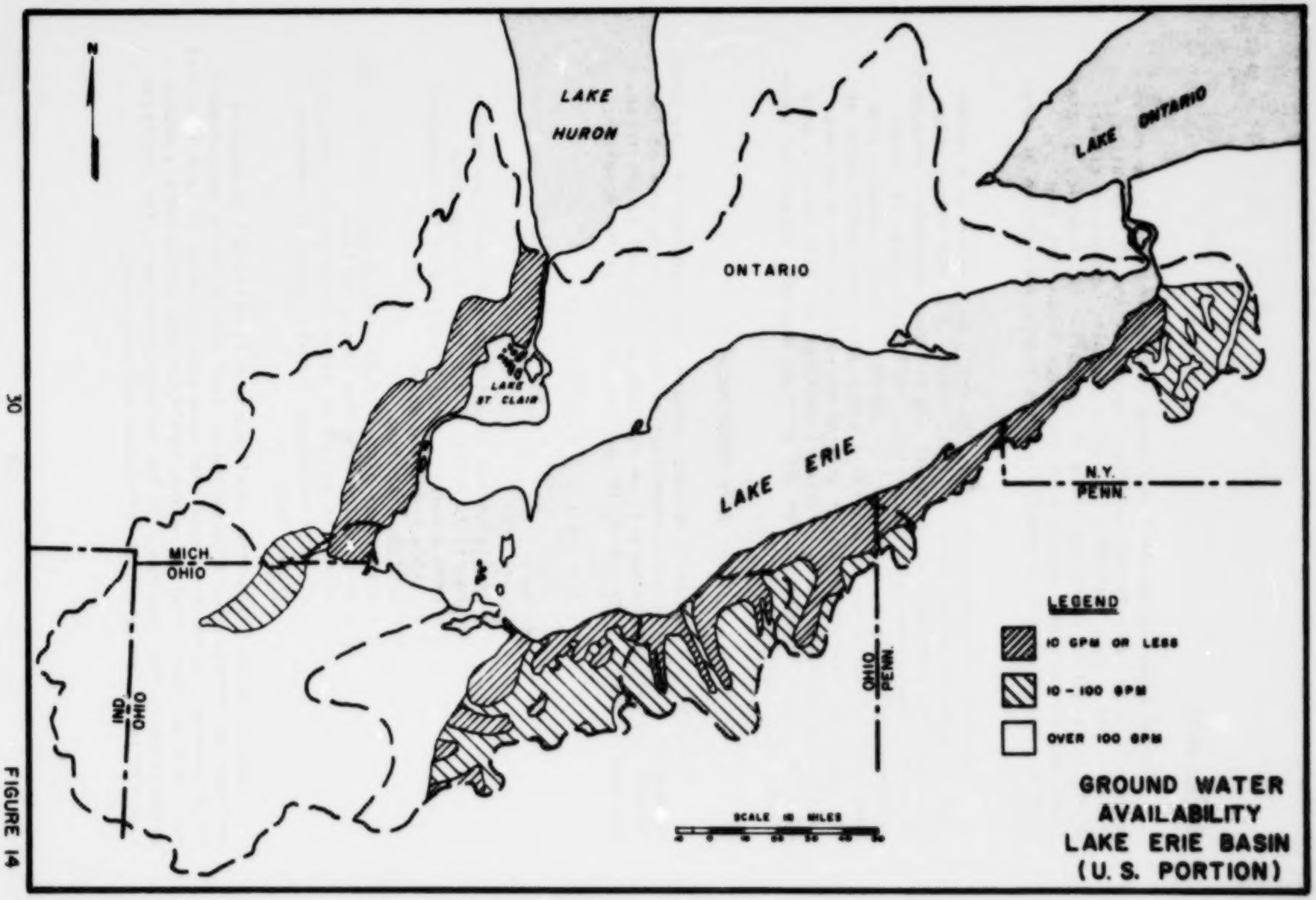
The water balance must be considered in the hydrology of Lake Erie. Because of a lack of precise quantitative information on some of the factors any proposed balance is an estimate and subject to criticism. The factors can be formulated, for a given period, in the equation:

$$P + R + U + I - \pm D - E - O = \Delta S$$

where:

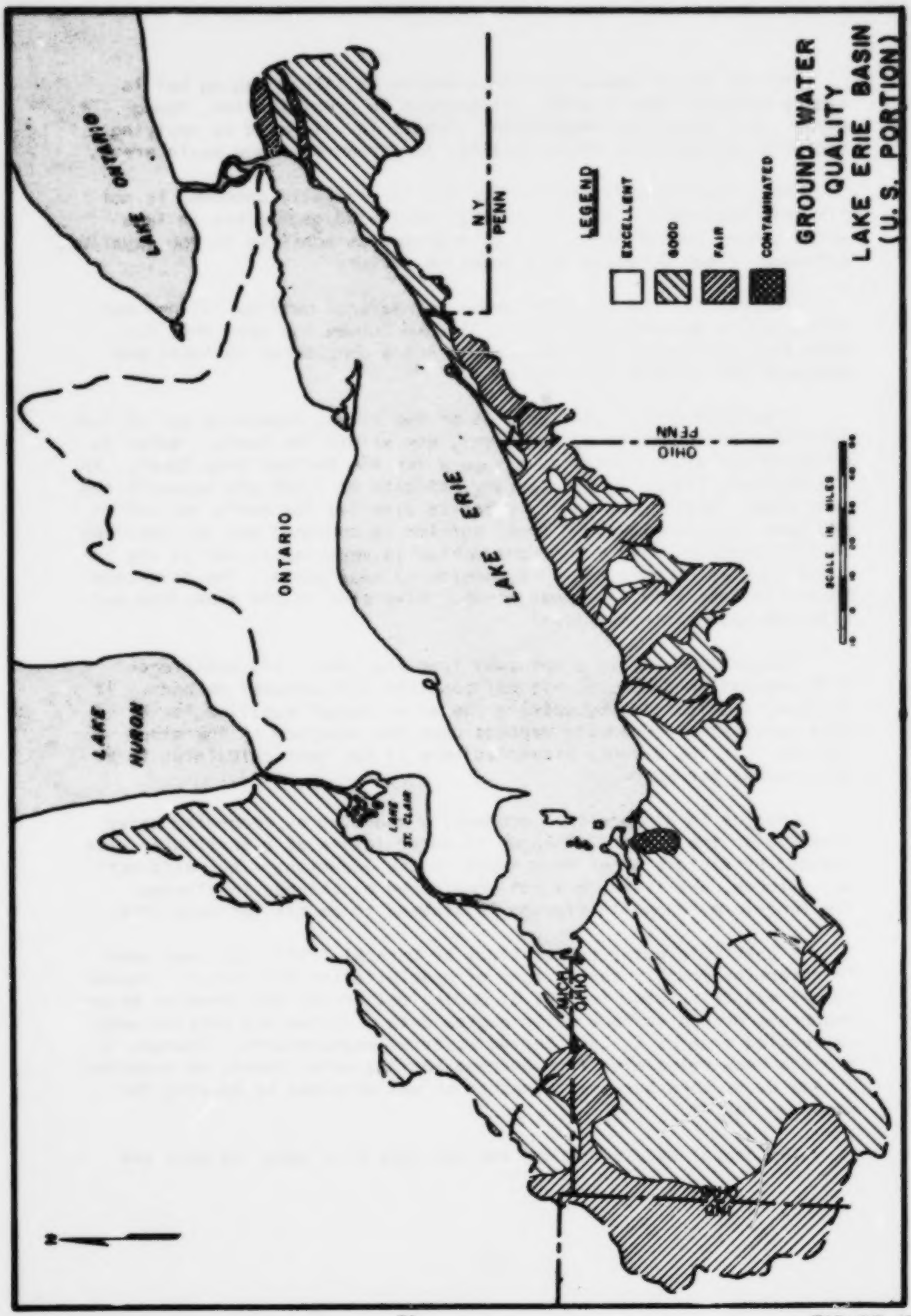
P = precipitation directly on the lake's surface
R = runoff from the lake's land drainage area
U = ground water - considered plus in the aggregate
I = inflow from lake above
O = outflow from lake
D = diversion; plus if into lake, minus if out of lake
E = evaporation from the lake's surface
ΔS = change in amount of water store in the lake; plus if supplies exceed removal, minus if removals exceed supplies

Precipitation (P) on the lake's surface is difficult to measure and must be interpolated from perimeter land precipitation measurements. It is generally considered that over-lake precipitation is less than that over land and precipitation on the lake's surface approximately equals evaporation in the long run. In the balance shown here, the precipitation (29 inches annually) at Put-in-Bay has been used.


N
LAKE HURON
LAKE ONTARIO
ONTARIO
LAKE ST CLAIR
LAKE ERIE
MICH.
OHIO
IND
OHIO
OHIO
PENN.
N.Y.
PENN.
LEGEND
10 GPM OR LESS
10 - 100 GPM
OVER 100 GPM
SCALE IN MILES

GROUND WATER
AVAILABILITY
LAKE ERIE BASIN
(U.S. PORTION)

FIGURE 14


LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
ONTARIO
LAKE ERIE
NY
PENN
OHIO
PENN
MICH
OHIO
IND
N
LEGEND
EXCELLENT
GOOD
FAIR
CONTAMINATED
SCALE IN MILES
10 0 10 20 30 40 50

GROUND WATER QUALITY LAKE ERIE BASIN (U.S. PORTION)

FIGURE 15

Runoff (R) is measurable to a degree by stream gaging but is highly variable due to areal differences in precipitation, topography, soil type, and vegetation. Runoff is estimated by applying factors, derived from stream gaging, to stream drainage basin areas.

The ground water contribution (U) is virtually unknown, is not directly measurable, and is usually considered negligible in lake water budget computations. It is regarded as positive in the equation, although it may actually be a negative factor.

Inflow (I) from the lake above and natural outflow (O) are not difficult to measure, and the U. S. Lake Survey has done this for more than 100 years. The measurements are considered reliable and adequate for balance calculations.

Diversion (D) in Lake Erie is of two kinds, diversion out of the basin and consumptive, or transient, use within the basin. Water is diverted out of the basin as a supply for the Welland Ship Canal. In the balance, the U. S. Lake Survey estimate of 7,000 cfs annually has been used. Within the basin, water is diverted for man's use out of and back into the lake. A small portion is consumed and not returned in this process. The total consumption is measurable, but in the total lake water balance it is considered negligible. The diversion factor in Lake Erie is always minus. Diversion to the lake from outside the basin is nonexistent.

Evaporation (E) is a net loss from the lake. Its measurement with unquestioned accuracy is not possible with present methods. It is usually calculated by solving the water budget equation for E. This calculation obviously depends upon the accuracy of the other factors. In the balance presented here it has been calculated to be 34.3 inches per year.

Changes in storage (ΔS) are easily measured by recording water levels over the period. Changes in water levels at a particular site induced by factors other than those in the equation; i.e., wind set-up, seiches, and tides, are not considered as changes in storage. The long-term change in storage is assumed to be nil for Lake Erie.

A Lake Erie water budget study by Derecki (1964) has been used to determine monthly percentages of precipitation and runoff. Annual runoff was calculated from U. S. Geological Survey and Canadian Water Resources Branch surface water gaging data. Inflow and outflow were calculated from U. S. Lake Survey reported measurements. Changes in storage were calculated from average monthly water levels as reported by the U. S. Lake Survey. Evaporation was obtained by solving the equation for it.

The annual supply sources for the Lake Erie water balance are detailed in Table 3. The relative importance of each of the tributaries to the Lake Erie water supply is graphically shown in Figure 16.

In the water balance table, Table 4, cubic feet per second (cfs) has been used for the unit of volume. The values shown can be converted to inches of water in Lake Erie by dividing by 735.

A study of the water balance indicates the following significant factors: (1) annual evaporation nearly equals runoff to the lake, (2) evaporation exceeds precipitation, (3) change in storage over a long period is not significant, and (4) evaporation is greatest in late winter and in autumn.

Calculations show that 80 percent of the net basin supply is derived from Lake Huron inflow via the Detroit River, 9 percent is precipitation upon the lake's surface, and only 11 percent is contributed by basin runoff. Loss of water from Lake Erie consists of 86 percent outflow, 3 percent diversion, and 11 percent evaporation.

LAKE LEVELS

Lake levels vary over short periods of time due to such phenomena as wind set-up, seiches, and lunar and solar tides. But, lake levels show changes in storage only when averaged over long periods of time. Changes in storage for Lake Erie reflect precipitation fluctuations over it and the upper Great Lakes. From 1860 (the beginning of U. S. Lake Survey records) to the present, change between minimum and maximum levels for Lake Erie has been 5.3 feet - almost nine percent of the lake's average depth.

Short-period fluctuations mentioned above are manifested, not by changes in volume, but by changes in the shape of the water mass. Tidal effects are negligible, but wind set-up and seiches may be quite pronounced, especially at the ends of the lake.

A wind set-up is the result of wind drag across the lake. Water is pushed toward the leeward shore in greater quantity than can be simultaneously returned in subsurface flow. The water rises at the leeward side and is depressed at the windward side. Lake Erie is particularly susceptible to high amplitude wind set-ups because of its shallowness and the orientation of its long axis parallel to predominant southwest and northeast winds. Amplitudes in excess of 13 feet have been recorded simultaneously between the ends of the lake during storms, with little change in level near the center of the lake.

In general the highest amplitude wind set-ups occur in spring and fall with northeasterly and westerly winds, respectively. Flooding and erosion are severe when high amplitude wind set-ups occur, and are

TABLE 3

WATER SUPPLY TO LAKE ERIE

Source	Supply (cfs)	Percent of Total Lake Supply	Percent of Basin Supply
Western Basin			
St. Clair River (Lake Huron, outflow)	187,450	79,774	92.921
Black, Pine, Belle Rivers	688	.293	.338
Clinton River	470	.200	.231
Rouge River	235	.100	.115
Thames River	1,840	.783	.903
Miscellaneous Runoff	1,799	.766	.883
Precipitation (Lake St. Clair)	919	.391	.451
Subtotal (Detroit River)	193,401	82.307	94.943
Huron River (Michigan	556	.237	.273
Raisin River	714	.304	.351
Maumee River	4,794	2.040	2.353
Portage River	403	.172	.198
Miscellaneous Runoff	1,271	.541	.624
Precipitation (Western Basin)	2,564	1.091	1.259
Subtotal	10,302	4.384	5.057
Total Western Basin	203,703	86.691	100.000
Evaporation	-3,042	-1.295	-1.493
Central Basin			
Western Basin	200,661	85.396	90.966
Sandusky River	1,021	.435	.463
Huron River (Ohio)	296	.126	.134
Vermilion River	228	.097	.103
Black River	302	.129	.137
Rocky River	273	.116	.124
Cuyahoga River	850	.362	.385
Chagrin River	333	.142	.151
Grand River (Ohio)	784	.334	.355
Ashtabula River	169	.072	.077
Conneaut Creek	257	.109	.117
Otter Creek	312	.133	.141
Kettle Creek	185	.079	.084
Miscellaneous Runoff	1,410	.600	.639
Precipitation (Central Basin)	13,508	5.749	6.124
Total Central Basin	220,589	93.877	100.000
Evaporation	-16,023	-6.819	-7.264

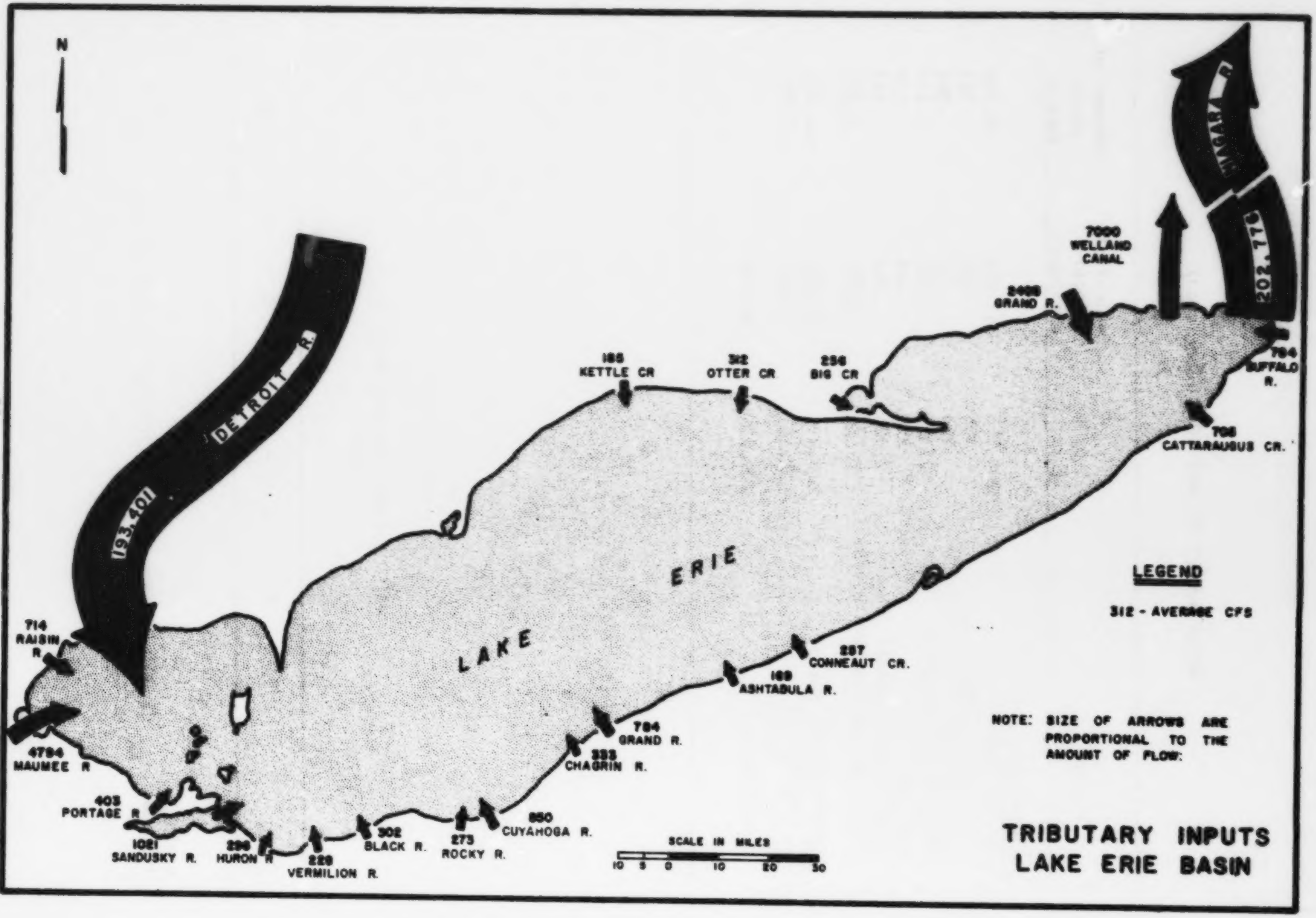
WATER SUPPLY TO LAKE ERIE (Concluded)

Source	Supply (cfs)	Percent of Total Lake Supply	Percent of Basin Supply
Eastern Basin			
Central Basin	204,566	87.058	94.746
Cattaraugus Creek	705	.300	.327
Buffalo River	784	.334	.363
Grand River (Ontario)	2,405	1.024	1.114
Big Creek	256	.108	.119
Miscellaneous Runoff	2,023	.861	.937
Precipitation (Eastern Basin)	5,172	2.201	2.395
Total Eastern Basin	215,911	91.886	100.000
Evaporation	-6,135	-2.611	-2.841
Lake Outflow	209,776	89.275	

TABLE 4

WATER BALANCE IN LAKE ERIE
(cfs)

	P +	R +	I -	O -	D -	E =	ΔS
Annual Average	22,000	25,~~000~~ 500	187,000	203,000	7,000	25,000	0



N
DETROIT R.
193,401
NIAGARA R.
202,776
7000
WELLAND
CANAL
2408
GRAND R.
794
BUFFALO
R.
706
CATTARAUGUS CR.
185
KETTLE CR
312
OTTER CR
256
BIG CR
LAKE
ERIE
LEGEND
312 - AVERAGE CFS
287
CONNEAUT CR.
169
ASHTABULA R.
794
GRAND R.
333
CHAGRIN R.
850
CUYAHOGA R.
273
ROCKY R.
302
BLACK R.
229
VERMILION R.
296
HURON R
1021
SANDUSKY R.
403
PORTAGE R
4794
MAUMEE R
714
RAISIN
R.
NOTE: SIZE OF ARROWS ARE PROPORTIONAL TO THE AMOUNT OF FLOW:
SCALE IN MILES
10
5
0
10
20
30

TRIBUTARY INPUTS
LAKE ERIE BASIN

FIGURE 16

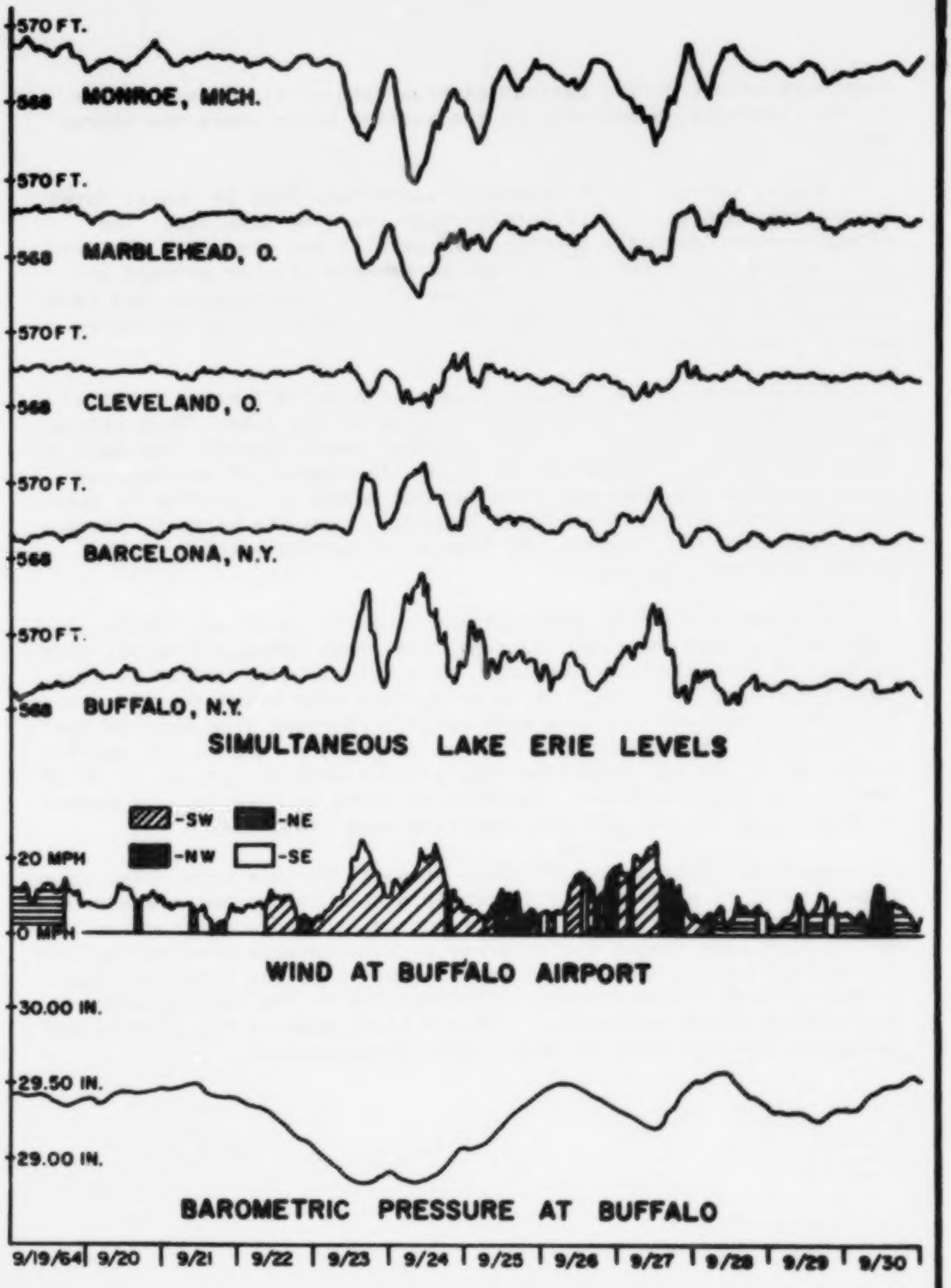
even more severe during periods of high lake levels (times of increased storage), especially in the western basin where the shores are low.

A wind set-up, which generally lasts less than 24 hours, forms a standing wave which will persist when the wind subsides. The standing wave, called a seiche, will persist and gradually diminish until another wind set-up. A typical example of wind set-ups and following seiches are shown in Figure 17 for simultaneous lake level readings at five different stations. Influencing winds and barometric pressure are also shown.

The primary seiche period of Lake Erie is 14.2 hours, that of the uninodal oscillation between the ends of the lake. This seiche period is nearly always apparent on water level records from west of Cleveland and east of Ashtabula, Ohio. Any number of seiches can exist together and each can have several nodes, giving rise to seemingly unintelligible water level records. Even the harbors, where most recorders are located, can have short-period seiches called surges or harbor resonance.

The shortest period oscillations of water level are simple surface waves caused by wind. In Lake Erie these waves ordinarily have periods of less than six seconds. Wave heights are limited by lake depths and fetch or length of water surface over which the wind blows. In general, maximum possible wave heights increase from west to east in Lake Erie. Waves over six feet in height are rare in the western basin, while similar conditions may produce wave heights of 15 to 20 feet in the eastern basin. Violence of waves in Lake Erie is caused by short wave lengths and the resulting wave steepness.

Waves are destructive to shore property in Lake Erie. The shoreline of Ohio is particularly susceptible because beaches are narrow and most banks are clay. Waves, of course, are more destructive during high lake stages and in areas of simultaneous wind set-up. In the western basin, wave action is believed to be the principal agent in maintaining the relatively high turbidity of the shallow water by stirring up bottom sediments. Table 5 lists some of the effects and causes of various kinds of water level disturbances.

 SIMULTANEOUS LAKE ERIE LEVELS

WIND AT BUFFALO AIRPORT

BAROMETRIC PRESSURE AT BUFFALO

LAKE LEVELS AND WINDS
SEPTEMBER, 1964

FIGURE 17

TABLE 5

CAUSES AND EFFECTS OF WATER LEVEL CHANGES

Water Level Disturbance	Cause	Effects: Navigation	Effects: Shore Property	Effects: Pollution
Stage	Precipitation Inflow	High - good Low - adverse	High - adverse Low - good	None
Wind Set-up	Wind	Same as above	Same as above	Lee - concentration Windward - dispersal
Seiche	Wind Set-up	Same as stage	Same as above	Dispersal
Tide	Moon - Sun	None	None	None
Waves	Wind	High - adverse Low - none	Adverse	Dispersion and longshore transport

LAKE WATER TEMPERATURES

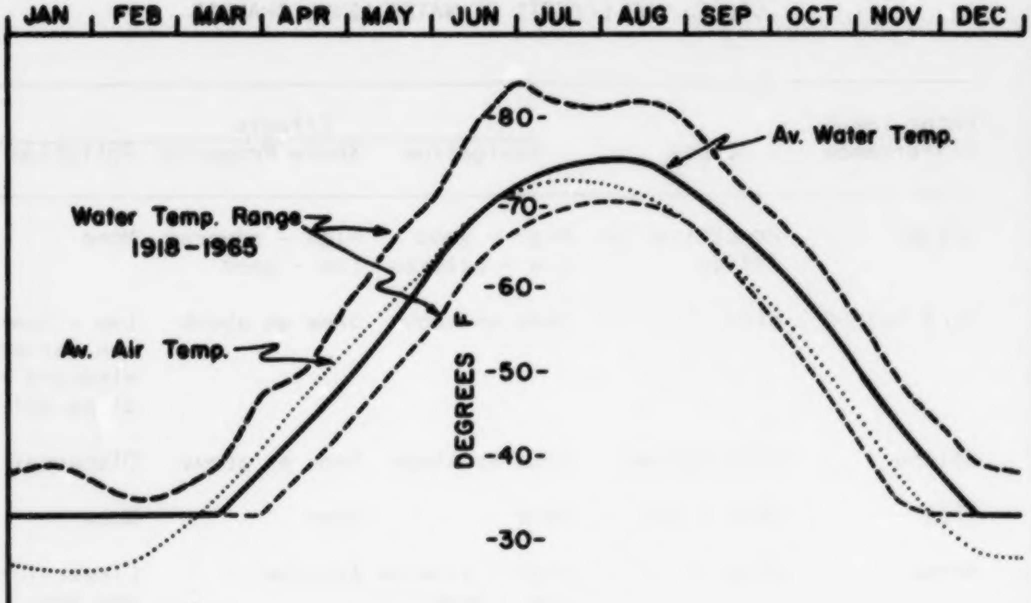
Lake Erie is the warmest of the Great Lakes. Mid-lake surface water reaches an average maximum of about 75°F (24°C) usually in the first half of August (Figure 18). Occasionally the summer temperature in mid-lake surface water rises above 80°F. Nearshore water normally reaches a maximum along the south shore of 80°F or more.

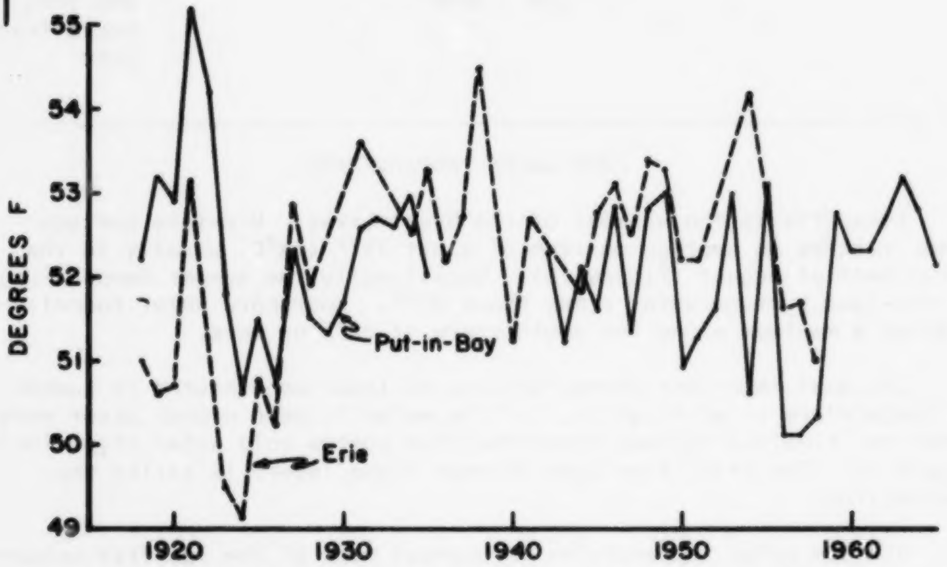
The most important characteristic of lake temperatures in summer is temperature stratification. If the water is deep enough upper warm water (epilimnion) becomes separated from bottom cold water (hypolimnion), Figure 19. The transition zone between these layers is called the thermocline.

Surface water temperatures throughout much of the ice-free seasons reflect water depth with temperature decreasing toward deep water (Rodgers, 1965). This inverse relationship changes to a direct relationship in the fall and early winter.

Water temperature is, of course, changed by variations in air

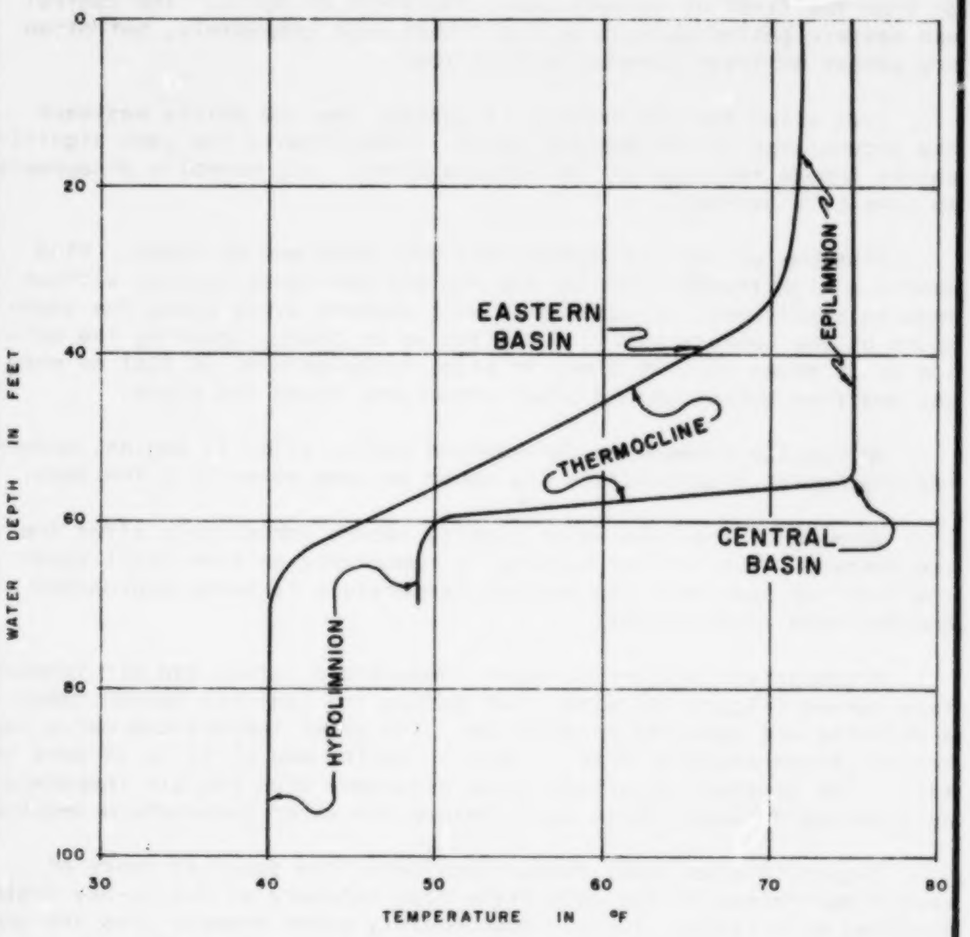
YEARLY WATER TEMPERATURE CURVE, PUT-IN-BAY, OHIO AND AIR TEMPERATURE AT TOLEDO, OHIO





ANNUAL AVERAGE WATER TEMPERATURES AT PUT-IN-BAY, OHIO AND ERIE, PENNSYLVANIA 1918-1965
(FROM OHIO DIV. OF WILDLIFE AND U.S. BUR. COMM. FISH. DATA)

FIGURE 18



TYPICAL SUMMER DEPTH
VS.
TEMPERATURE IN LAKE ERIE

FIGURE 19

temperature, and the relationship is direct. Slight modifications to the relationship are caused by the amount of sunshine, strength and duration of winds, and by humidity.

Lake Erie water temperature, in the western basin, falls to 33°F normally about the middle of December and remains at that level until the middle of March. Usually the western basin freezes over completely. The surface water in the remainder of Lake Erie is at 33°F for about the same length of time, but normally about two weeks later, or from the first of January until the first of April. The central and eastern basins usually do not freeze over completely, but often are almost entirely covered by floe ice.

Just after the ice breakup in spring, the ice drifts eastward and accumulates in the eastern basin. Occasionally ice jams significantly impede the flow of the Niagara River. Ice normally disappears in Lake Erie by May 1.

Windrows of ice are common near the shore and on reefs. Wind exerts a significant force on the ice and can cause breakup without thawing conditions. Occasionally with onshore winds along the south shore of the western basin, ice piles up on shore, scouring the bottom as it moves in. At times it piles to heights of 30 feet or more and destroys buildings and other structures along the shore.

Spring ice breakup in the western basin, after it begins, occurs rapidly, going from complete ice cover to open water in a few days.

Warming of the lake water usually begins immediately after the ice breakup. The rate of warming is remarkably uniform until about the first of July when the maximum temperature is being approached and the rate flattens out.

A comparison of surface water temperature curves and air temperature curves (Figure 18) shows that during the ice-free season there is a definite and expected parallelism. The water temperature curve lags the air temperature by 9 to 12 days in spring and by 12 to 15 days in fall. The greatest departure is in midsummer when the air temperature decline begins about three weeks before the water temperature decline.

Figure 18 also shows temperature data from about 45 years of record maintained at the Ohio State Fish Hatchery at Put-in-Bay (Ohio Division of Wildlife, 1961). Mean monthly water temperatures are shown. Also annual average temperatures are shown for the period for Put-in-Bay and for the Erie, Pennsylvania water intake as compiled by the U. S. Bureau of Commercial Fisheries. The Erie record shows a trend toward higher temperatures during the period and the Put-in-Bay record shows a trend toward lower temperatures. Trends appear insignificant, however, especially since accuracy of measurement is at least questionable.

Temperature of the surface water of Lake Erie is of less significance than the three-dimensional temperature structure. This structure influences circulation of the water and its dissolved and suspended substances, and also has a marked influence on the chemical and biochemical activity at the bottom sediment-water interface.

WESTERN BASIN

Figures 20a, b, and c diagrammatically show the development of seasonal temperature structure in each of Lake Erie's three basins. Figure 20a for the western basin shows the simplest thermal structure. In spring the temperature of the entire water column rises gradually. In summer the water is usually nearly isothermal vertically. A transient secondary thermocline of little importance can be formed near the surface during hot calm periods. During periods of normal winds and above average air temperatures, a thermocline can be formed near the bottom, simultaneously with the development of a secondary thermocline in the central basin. This thermocline is accompanied by rapid deoxygenation of the bottom water due to oxygen-consuming material and the inability of oxygen to penetrate the thermocline.

Storms equalize temperatures in the western basin top to bottom. In August when cooling begins, the western basin water is vertically isothermal and remains so as it cools in fall and winter.

CENTRAL BASIN

The central basin water, Figure 20b, has a simple fall, winter, and spring thermal structure. In summer the structure is more complex than in the western basin. The temperature at the beginning of the first summer weather cycle in early June is approximately the temperature of the following hypolimnion.

The stable thermocline and hypolimnion are formed relatively suddenly during the first storm ending this weather cycle. The intensity of this storm determines the depth of the thermocline, and the thermocline remains at approximately its initial elevation until the lake begins to cool in August. The thermocline is normally tilted slightly upward to the north. During its existence the hypolimnion loses oxygen and may lose it all because it does not mix with the water above, and it contains oxidizable organic matter.

Summer weather cycles cause the epilimnion to alternate in structure between one layer and three layers. Storms equalize the temperature of the epilimnion. During the following warming period a secondary thermocline is formed by heat input and the mixing by normal winds to a depth of 6 or 7 meters. While this is forming the temperature of the epilimnion below this temporary thermocline is not changing. The temperature of this zone is then raised suddenly during the cycle-ending storm when the temperature of the entire epilimnion again becomes

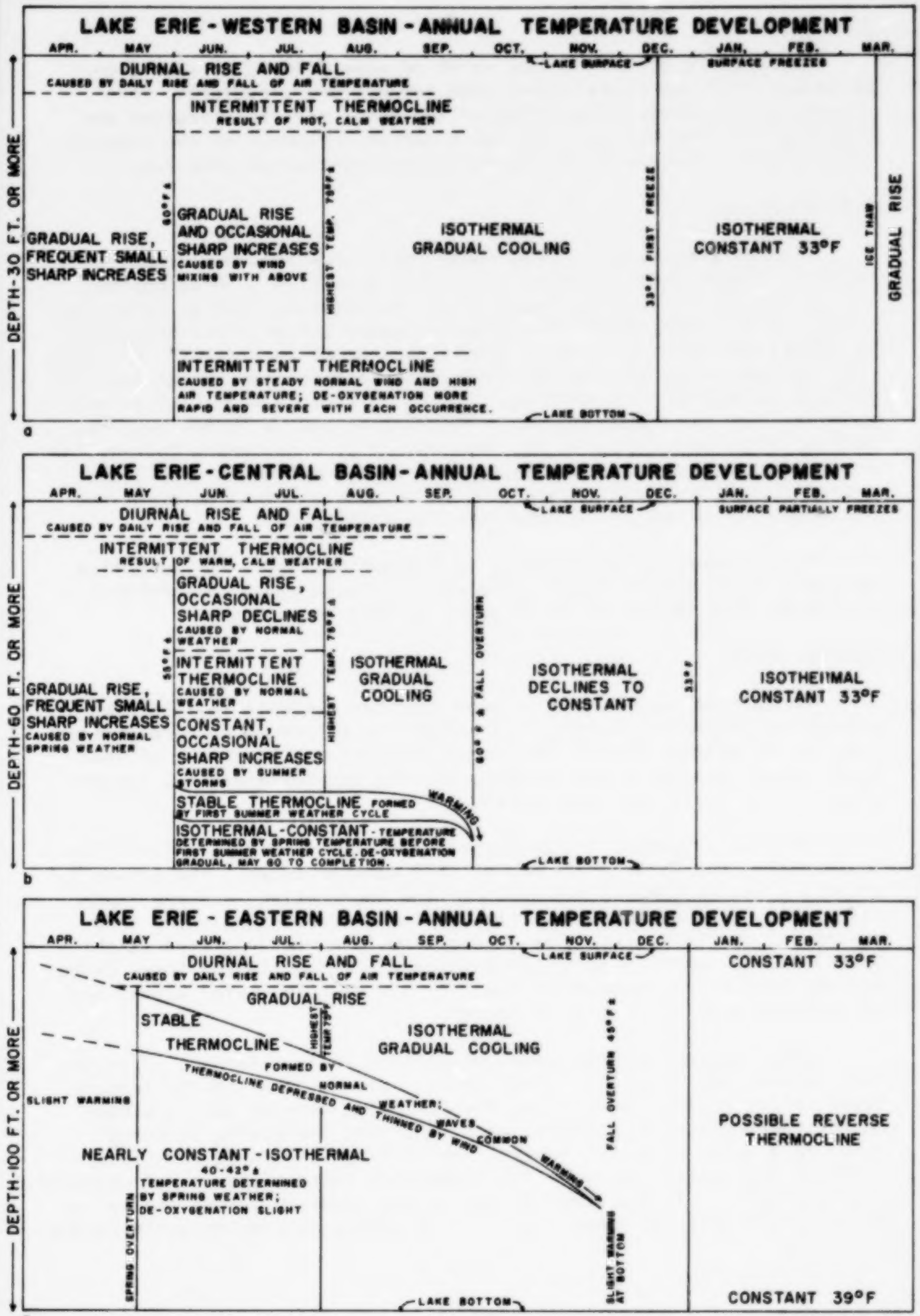
 LAKE ERIE - WESTERN BASIN - ANNUAL TEMPERATURE DEVELOPMENT
APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR.
LAKE SURFACE
SURFACE FREEZES
DIURNAL RISE AND FALL
CAUSED BY DAILY RISE AND FALL OF AIR TEMPERATURE
INTERMITTENT THERMOCLINE
RESULT OF HOT, CALM WEATHER
DEPTH-30 FT. OR MORE
GRADUAL RISE, FREQUENT SMALL SHARP INCREASES
60°F ±
GRADUAL RISE AND OCCASIONAL SHARP INCREASES
CAUSED BY WIND MIXING WITH ABOVE
HIGHEST TEMP. 75°F ±
ISOTHERMAL GRADUAL COOLING
33°F FIRST FREEZE
ISOTHERMAL CONSTANT 33°F
ICE THAW
GRADUAL RISE
INTERMITTENT THERMOCLINE
CAUSED BY STEADY NORMAL WIND AND HIGH AIR TEMPERATURE; DE-OXYGENATION MORE RAPID AND SEVERE WITH EACH OCCURRENCE.
LAKE BOTTOM
a
LAKE ERIE - CENTRAL BASIN - ANNUAL TEMPERATURE DEVELOPMENT
APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR.
LAKE SURFACE
SURFACE PARTIALLY FREEZES
DIURNAL RISE AND FALL
CAUSED BY DAILY RISE AND FALL OF AIR TEMPERATURE
INTERMITTENT THERMOCLINE
RESULT OF WARM, CALM WEATHER
DEPTH-60 FT. OR MORE
GRADUAL RISE, OCCASIONAL SHARP DECLINES
CAUSED BY NORMAL WEATHER
55°F ±
INTERMITTENT THERMOCLINE
CAUSED BY NORMAL WEATHER
GRADUAL RISE, FREQUENT SMALL SHARP INCREASES
CAUSED BY NORMAL SPRING WEATHER
CONSTANT, OCCASIONAL SHARP INCREASES
CAUSED BY SUMMER STORMS
HIGHEST TEMP. 75°F ±
ISOTHERMAL GRADUAL COOLING
60°F ± FALL OVERTURN
ISOTHERMAL DECLINES TO CONSTANT
33°F
ISOTHERMAL CONSTANT 33°F
STABLE THERMOCLINE FORMED BY FIRST SUMMER WEATHER CYCLE
WARMING
ISOTHERMAL-CONSTANT - TEMPERATURE DETERMINED BY SPRING TEMPERATURE BEFORE FIRST SUMMER WEATHER CYCLE. DE-OXYGENATION GRADUAL, MAY GO TO COMPLETION.
LAKE BOTTOM
b
LAKE ERIE - EASTERN BASIN - ANNUAL TEMPERATURE DEVELOPMENT
APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR.
LAKE SURFACE
DIURNAL RISE AND FALL
CAUSED BY DAILY RISE AND FALL OF AIR TEMPERATURE
CONSTANT 33°F
GRADUAL RISE
STABLE
THERMOCLINE
HIGHEST TEMP.
ISOTHERMAL GRADUAL COOLING
FORMED BY NORMAL WEATHER; WAVES COMMON
THERMOCLINE DEPRESSED AND THINNED BY WIND
WARMING
DEPTH-100 FT. OR MORE
SLIGHT WARMING
FALL OVERTURN 45°F ±
POSSIBLE REVERSE THERMOCLINE
NEARLY CONSTANT - ISOTHERMAL
40-42°±
TEMPERATURE DETERMINED BY SPRING WEATHER; DE-OXYGENATION SLIGHT
SPRING OVERTURN
SLIGHT WARMING AT BOTTOM
LAKE BOTTOM
CONSTANT 39°F
c

FIGURE 20

uniform. The density gradient at the stable thermocline is thus increased. The whole process is repeated several times before August. Figure 21 shows the summer cyclic development at station E-8 (Figure 23) in the central basin. In August the epilimnion begins to cool and loses its three-layer structure. The density gradient at the thermocline decreases and the thermocline deepens, disappearing entirely by October.

Upwelling, downwelling, and internal waves are created during summer storms in the central basin, especially during northwesters. The hypolimnion slides around in the basin. This water movement probably brings bottom sediments into suspension and this may increase oxygen consumption, bringing about relatively sudden oxygen depletion in the hypolimnion. Internal waves other than up and downwelling in the central basin probably have amplitudes of less than five feet, as indicated by a study in the summer of 1965. Periods range from less than five minutes to two weeks or more, with an inertial period near eighteen hours apparently predominant.

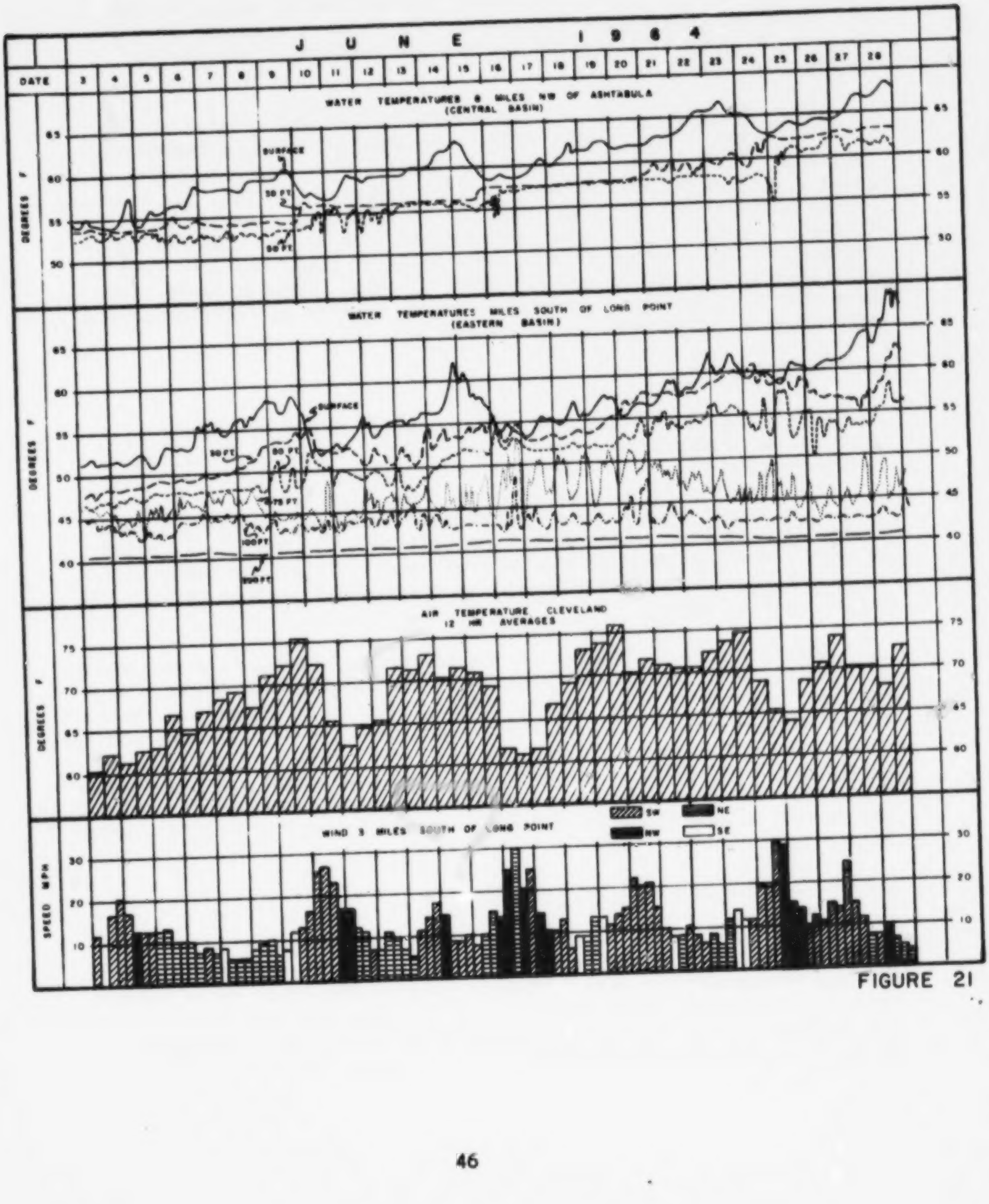
EASTERN BASIN

The temperature structure of the eastern basin is probably like that of the deeper Great Lakes, Figure 20c. In winter it is nearly isothermal and may have reverse stratification. In spring it mixes top to bottom and is vertically isothermal. The upper waters warm gradually and a shallow thick thermocline forms early, thinning and deepening as summer progresses. The epilimnion is mixed more often or more constantly than in the central basin. Figure 21 shows a typical summer thermal development at station E12 and E14 (Figure 23) in the eastern basin.

Mixing in the epilimnion of the eastern basin may be aided greatly or perpetuated by relatively high amplitude thermoclinal waves. Significant internal wave motion is virtually constant throughout the summer with an inertial 17 to 18-hour period dominant. The thermocline thins and deepens rapidly after the epilimnion begins to cool. Just before the thermocline disappears, usually in November, it has reached a depth of 100 feet or more. With its disappearance the hypolimnion zone warms somewhat, due to mixing, and then begins to cool to winter temperatures.

NEARSHORE WATER TEMPERATURES

Temperature plays an important role in nearshore waters. The significance is not great in winter because the temperature is nearly uniform throughout the lake. However, during the other three seasons waters of different temperatures are in contact and density interfaces are formed, inhibiting mixing processes and resulting in currents which would not otherwise exist.


J U N E 1 9 6 4
DATE
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19
20
21
22
23
24
25
26
27
28
WATER TEMPERATURES 8 MILES NW OF ASHTABULA
(CENTRAL BASIN)
DEGREES F
65
60
55
50
SURFACE
30 FT
50 FT
WATER TEMPERATURES MILES SOUTH OF LONG POINT
(EASTERN BASIN)
DEGREES F
65
60
55
50
45
40
SURFACE
30 FT
50 FT
75 FT
100 FT
200 FT
AIR TEMPERATURE CLEVELAND
12 HR AVERAGES
DEGREES F
75
70
65
60
SW
NE
NW
SE
WIND 3 MILES SOUTH OF LONG POINT
SPEED MPH
30
20
10

FIGURE 21

During the spring and summer, and strongly in the spring, a temperature differential may exist between nearshore and offshore waters. The water within a mile or so off shore is usually considerably warmer. The greatest differential appears to exist along the south shore of the central basin. The primary reasons for this are warm tributary discharges and the southwest winds over the lake pushing warm surface waters toward the right of the wind or toward the south shore. North shore nearshore waters do not appear to be greatly warmer than mid-lake water at any time of the year. The prevailing southwest winds here too may be largely responsible.

There is less lateral variation in the eastern basin in water temperatures, probably because of less tributary input and deeper nearshore water. The warmest water there is also normally along the south shore in spring and summer.

The nearshore temperature structure in spring and summer indicates an eastward movement of south shore nearshore water. The physics of the system require this movement. Current measurements at several nearshore stations have confirmed it.

In the western basin the disruptive influences of the Detroit River inflow, bottom topography and the islands do not allow the development of the same nearshore thermal structure. Figure 22 shows a typical temperature distribution in the western basin in early summer.

EFFECTS OF TEMPERATURE PHENOMENA

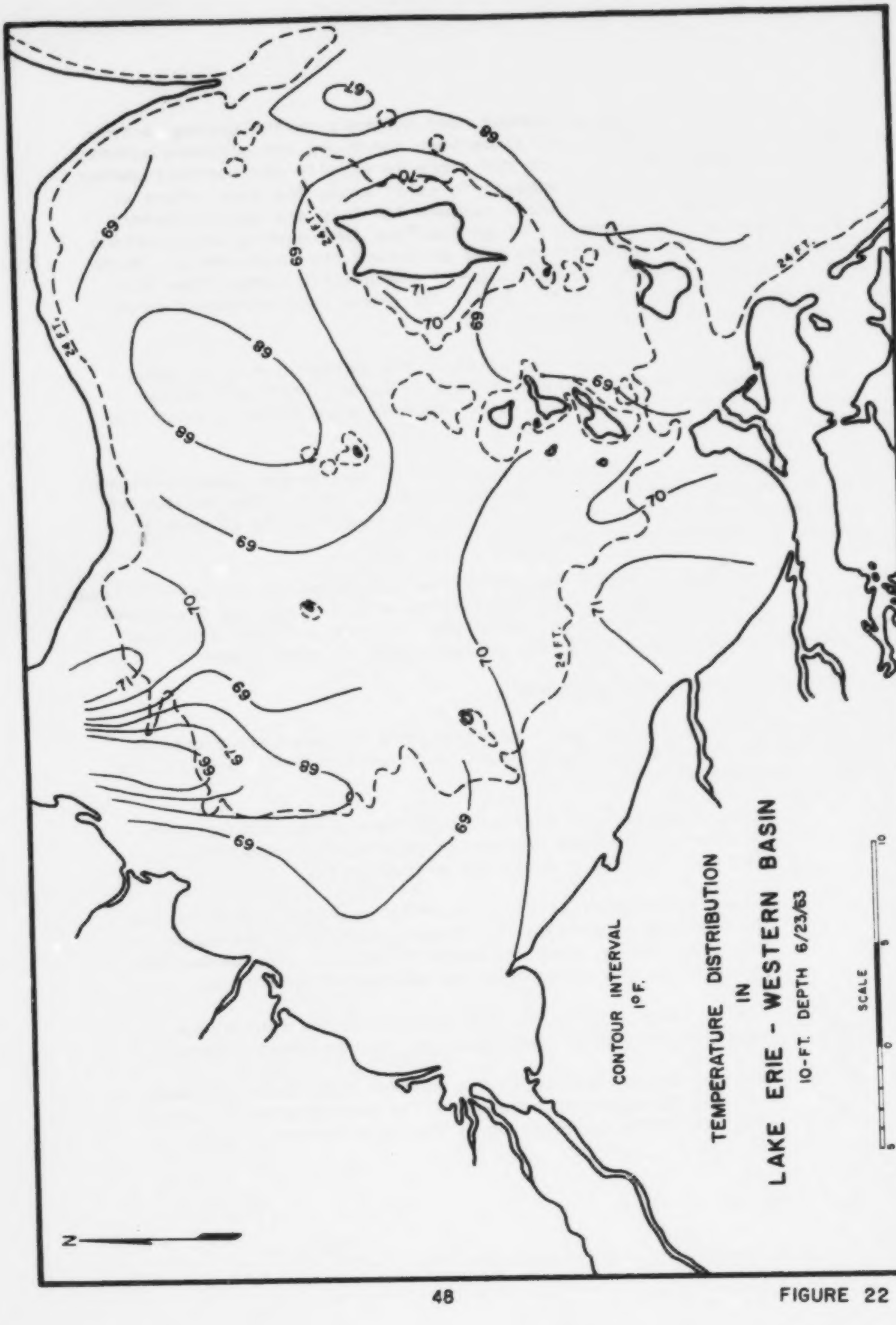
Temperature plays a most important role in Lake Erie processes as does the temperature-related density stratification. Some of the more important effects are:

1. Actual temperature controls plant and animal productivity of the lake to some degree; in general the higher the temperature, the greater the productivity.

2. Intermittent thermal stratification near the bottom of the western basin leads to rapid deoxygenation of the water in the hypolimnion, when and where it occurs. The warmer the hypolimnion the more rapid the deoxygenation will be.

3. Stable summer thermal stratification in the central basin leads to the annual deoxygenation of hypolimnetic water.

4. Thermal stratification in the eastern basin does not have serious consequences because of the much greater thickness and less rapid circulation of the hypolimnion.


TEMPERATURE DISTRIBUTION
IN
LAKE ERIE - WESTERN BASIN
10-FT. DEPTH 6/23/63

CONTOUR INTERVAL
1°F.

SCALE
5
0
5
10
N
24 FT.
67
68
69
70
71
66

FIGURE 22

5. Temperature is important in controlling water movements in nearshore areas. Density barriers may confine warmer waters and pollution substances to the nearshore zones, especially along the south shore, in spring and summer.

6. Temperature rises in general limit top to bottom mixing; temperature declines favor it.

LAKE CURRENTS

Two basic types of circulation exist in Lake Erie: (1) Horizontal motion and (2) essentially vertical motion. Each of these can be genetically subdivided as follows:

Horizontal Currents	Vertical Currents
(1) Lake flow-through	(1) Temperature gradient (convection)
(2) Wind-driven	(2) Turbidity gradient
(3) Seiche	(3) Dissolved solids, gradient
(4) Inertial	(4) Convergence of horizontal currents
(5) Density	(5) Divergence of horizontal currents
(6) Turbulence	(6) Turbulence

Generally more energy is involved in horizontal than in vertical currents. All currents tend to relocate and disperse suspended or dissolved constituents. The movement may be quite different between offshore and nearshore waters because of the effects of bottom topography and boundary conditions.

The lake flow-through current is always a net movement eastward. This, however, does not mean that, at all places at all times, a flow-through component is included. It is possible that this component of water movement is found only on one side of the lake or that it wanders from one side to the other. Throughout the water column, it should be essentially uni-directional, with no compensating return flow. All other types of currents are superimposed and, except in restricted channels, the flow-through may be completely masked.

The flow-through current of Lake Erie can be considered as the most significant agent in distribution of dissolved substances because most of these substances are introduced near or at the source of the flow-through. Because of its generally very low velocity, it is not significant in the transport of suspended material. The exceptions are in restricted channels.

Wind-driven currents are, as the term implies, the movements of water directly caused by wind stress at the water surface. These currents are the fastest and the most variable in direction of the large-scale water movements. Large volumes of water can be moved in a very short time, as in wind set-up.

The first effect of wind is to produce waves. Waves, in themselves, are not significant transporters of water, at least in deeper areas of the lake. Most of the motion is orbital in a vertical plane decreasing downward from the surface to zero at a depth equal to the wave length. There is only a slight net transport of water in the direction of wave progress. However, when waves reach shallow ater (half the wave length or less) they change from orbital to a to and fro motion. The slight net transport still exists and along with the effects of gravity on the return flow and wind drag, littoral or longshore currents are created. Such currents can be especially rapid when the wave approach is toward shore at some angle other than normal.

Waves in mid-lake (also along shore) can produce turbulence and if the water is shallow enough, bottom sediments may be thereby brought into suspension. In deep water this is not a significant agent, in itself, for transport of sediment. It may be looked upon as an agent for mixing essentially in situ. However, wave turbulence may bring sediment up into the water to be transported by other currents.

The second effect of wind is to drag, en masse, a volume of water more or less in the direction of the wind. This is probably the major factor in wind set-up. The drag decreases with depth and so does the imposed velocity. If the volume of water moved cannot escape from the lake, two things will happen: (1) the water level will rise at the leeward end of the lake and (2) a subsurface return flow will be created. If there is adequate depth so that there is an unrestricted return flow, the rise in level will be small. In Lake Erie the water is shallow, the return flow is restricted, and the disturbance of water level is pronounced.

The above description of wind-driven currents is greatly oversimplified. The currents are influenced by the Coriolis effect, by previously established wind-driven currents, by water temperature, by air temperature, by the local and overall shape of the basin, by the force of the wind, by the distance of wind travel over water (fetch), and by the direction and duration of the wind.

Seiche currents are those created in the standing wave motions of seiches. Seiches, of course, depend upon the wind (rarely atmospheric pressure change along) for their creation. After the wind set-up, a seiche and its currents are self-sustaining. They degenerate by friction. Degeneration is seldom, if ever, complete because seiches are normally rejuvenated and/or changed by the wind.

The highest velocity seiche currents in a symmetrical basin occur along and normal to the nodal line of a particular seiche, and the velocity decreases to a minimum at the locations of maximum amplitude. Superimposed and multinodal seiches can lead to complex and seemingly unintelligible motions. In Lake Erie the longitudinal seiche dominates and the motions associated with it over-ride the others. Currents reach significant velocities in the nodal zone (roughly across the lake from Fairport, Ohio) and in the inter-island channels.

Seiche currents apparently do not result in a net transport of water; the motion is to and fro and balancing.

Density currents are those resulting when water of a different density is brought into the lake. Density differences can result from temperature differences, differences in dissolved solids content, differences in suspended solids content, or any combination of these.

Density currents are the most apparent and probably have their greatest importance in boundary waters. They provide a mechanism for a more rapid horizontal distribution of tributary inputs than would otherwise occur. When tributaries are warmer than the lake, the inputs can override the lake water, and vice versa. In either case the inputs can spread widely offshore. Density currents from differences in dissolved solids or suspended solids content nearly always tend to force input water to under-run lake water. If however, the solids-laden water is of high enough temperature, it can override the lake water, and this often happens in Lake Erie. Paradoxically, density differences in a vertical plane can often be sustained, especially with water temperatures near 4°C (39°F), the temperature of maximum density, preventing lateral dispersion and confining inputs to the nearshore zone.

Density currents are not compensating. Their movement is ordinarily offshore with no return of the same water.

Turbulence, to some degree, is associated with all other types of currents. This is more or less random motion, with horizontal and vertical components. Its main effect might be considered as that of mixing or dispersion, in that a given volume of water will, after a given time, be found throughout a much larger volume. Turbulent motion is most pronounced when associated with wind-driven currents.

Convection is vertical circulation caused by heat transfer. It is important in Lake Erie during the cooling period from August to January. The surface water loses heat to the atmosphere, becomes colder than lower water, and sinks. Warmer water rises to replace it. This process continues until the water column reaches 4°C, the temperature of maximum density. This kind of circulation probably cannot be called currents in the strictest sense, but it is highly effective in exchanging water between the surface and bottom. Heat loss from the water is the only factor needed to sustain this kind of motion.

Convection currents are of little consequence during the warming months, with the possible exception of short periods of colder air temperatures during storms. The over-running of cold water from tributaries can cause convection currents, but this is not common.

Turbidity and dissolved solids gradients can cause vertical circulation if, like over-running of cold water, they can be formed with the denser water on top. This situation is not normal.

Convergence of horizontal currents can cause vertical movement if at some lower or higher level there are diverging currents. Converging surface currents lead to downward movement. Diverging surface currents lead to upward movement.

Turbulence, associated with storm activity, is the most effective vertical motion at all seasons of the year. The result is rapid, vertical mixing in unstratified water from top to bottom, and above the density barrier if the water is stratified.

Currents in Lake Erie have been studied from time to time since before the turn of the century. Most studies have been largely confined to the western basin of the lake.

Only one attempt has been made in the past to show the general water circulation pattern for the entire lake. This was by Harrington (1895).

Circulation in the western basin has been investigated by several workers, including Harrington (1895), Wright (1955), Olson (1950), Verber (1953, 1954), and recently by the U. S. Bureau of Commercial Fisheries. The eastern basin has been neglected except for a rather local study in the Long Point area by Green (Fish, 1960).

The Federal Water Pollution Control Administration measured currents continuously and synoptically at selected locations in the western, central, and eastern basins. The U. S. Lake Survey has also similarly measured currents near a few selected harbors on Lake Erie. These programs are the first of their kind in Lake Erie.

Nearly all past work has relied upon data gathered from the release of drift cards, drift bottles, and shallow drogues. Only a very small amount of metering has been done, and this was by manual methods. Some attempts have been made to map chemically or physically different water masses, thereby inferring water circulation, in the western basin.

Harrington (1895), using drift bottles, deduced the surface currents of Lake Erie. In the western basin he showed the Detroit River fanning out from the Michigan shore to the Canadian shore. The eastern half of the Detroit River flow went directly to Pelee Passage. The remainder apparently flowed south and eastward to discharge through the South Passage with a small amount going northward to Pelee Passage. He also showed a clockwise movement around Pelee Island and a counter-clockwise movement around Kelleys Island.

Olson (1950) made a study of surface currents in western Lake Erie in 1948 and 1949 using drift cards. He divided the Detroit River flow into three parts, which he called the "Colchester Convergence", the "Pigeon Bay Drift", and the "Pelee Passage Drift" (See Figure 1). This implies that the Detroit River flow stays along the north shore, passing into the central basin via Pelee Passage. He showed a drift toward shore along the Michigan shore and indeterminate flow along the south shore. He stated that Maumee River water must flow through South Passage or between the islands, but indicated a to and fro motion in those channels. He also showed a clockwise movement around Pelee island which he called the "Pelee Island Gyre".

Wright (1955) studied the surface currents of western Lake Erie in 1928 using drift bottles. He drew no conclusions except to state that surface currents were not constant but were highly dependent upon the wind. Most of his bottles released near the Ohio and Michigan mainland shores went southward while most bottles released just west of the islands went northward.

Verber (1953, 1954), using drift cards, drogues, and a current meter in the inter-island channels, concluded that a rotational movement of water existed in western Lake Erie. Measurements in Pelee Passage, at depth as well as at the surface, indicated a larger outflow from the western basin than inflow in that channel and vice versa in the southern channels. He also concluded that most of the Detroit River water moved eastward through Pelee Passage.

The U. S. Bureau of Commercial Fisheries in recent work, using drogued drift bottles for measurement, indicated that surface currents in western Lake Erie are dependent upon winds. Southerly winds push the surface water toward the north shore and Pelee Passage. Westerly and northwesterly winds result in a flow pattern more or less similar to that of Harrington with Detroit River water reaching deep into the basin. Northeast winds push water toward the west shore with a simultaneous flow out of the Pelee Passage.

The Detroit Project, FWPCA, investigated currents near the mouth of the Detroit River and along the Michigan shore with dye and drogues. They deduced that outside the influence of river flow that currents were controlled by and essentially followed the wind direction.

The Ohio Department of Natural Resources (Hartley, Herdendorf, and Keller, 1966) measured conductivity and temperature in a dense pattern in the western basin on 23 June 1963. They indicated that the main part of the Detroit River flow extended far southward into the basin at the surface and at depth. The west part of the river followed the Michigan and Ohio shores moving northward west of the islands. The east part of the Detroit flow appeared to be moving east along the Canadian shore. The bulk of the western basin water was moving out through the Pelee Passage.

The only published work attempting to describe the circulation of central Lake Erie is that of Harrington (1895). He showed a general down-lake surface flow with a counter-clockwise gyre between Point Pelee and Pointe Aux Pins, Ontario, and East of Pointe Aux Pins. He also showed the gyre around Pelee Island extending several miles into central Lake Erie.

Green (Fish, 1960) measured currents at a few isolated sites in central Lake Erie in 1929 without showing significant movements.

The U. S. Bureau of Commercial Fisheries recent work with shallow drogues indicates eastward flow in nearly all cases in mid-lake. They indicate that the Pelee Passage discharge reaches the Ohio shore between Sandusky and Lorain.

The Ohio Department of Natural Resources, with some direct measurements in the southeastern part of the basin indicates that complex patterns of water movement may exist both areally and in depth. Also their work indicates that eddies are common around harbor breakwaters which are not shore-connected. This has been confirmed by the U. S. Lake Survey in their harbor work.

Even less is known of eastern basin water circulation. The only known past attempt to measure currents in the eastern basin was by Green in 1929 as reported by Fish (1960). Green used a current pole and a Price current meter to measure velocities in the deeper water of the basin. He admitted that his measurements at depth were probably too high in value. In general he found, on the few occasions of measurement, that there was a rather rapid flow eastward, especially near Long Point. He also found that surface flow opposed the wind quite often. Flow patterns, other than eastward dominant movement cannot be shown from his data.

Drift bottles, drift cards and shallow drogues, released by the U. S. Bureau of Commercial Fisheries and the Ohio Department of Natural Resources in the western and central basins in recent years, have arrived on Long Point and the south shore of the eastern basin in great numbers. Only a few drifted to the north shore of the eastern basin east of Long Point. This probably indicates an eastward cross-lake flow of surface water.

In order to further describe the prevailing circulation patterns, the U. S. Public Health Service (now the Federal Water Pollution Control

Administration), in May 1964, established a system of automatic current metering stations in Lake Erie. The metering program was maintained until September 1965. The station locations and kinds of measurements are shown on Figure 23. Table 6 lists the stations, the depths at each meter, and the time of station occupancy. Temperature recorders were installed in conjunction with the current meters. Wind recorders were installed on most stations, but only during summer.

The metering program could not describe currents very near the lake bottom. Therefore, in the summer of 1965 seabed drifters were released at selected locations in Lake Erie (Figure 24). These small drifters contained instructions to return to the sender.

Intensive, localized, short-term drogue studies were made near the mouth of the Detroit River and off western Cleveland in the summer of 1964. These were made to learn something of lake dispersion and local currents.

Dye studies of short duration were carried out near the mouths of several tributaries along the south shore of the central basin during the summer of 1965, using Rhodamine B dye.

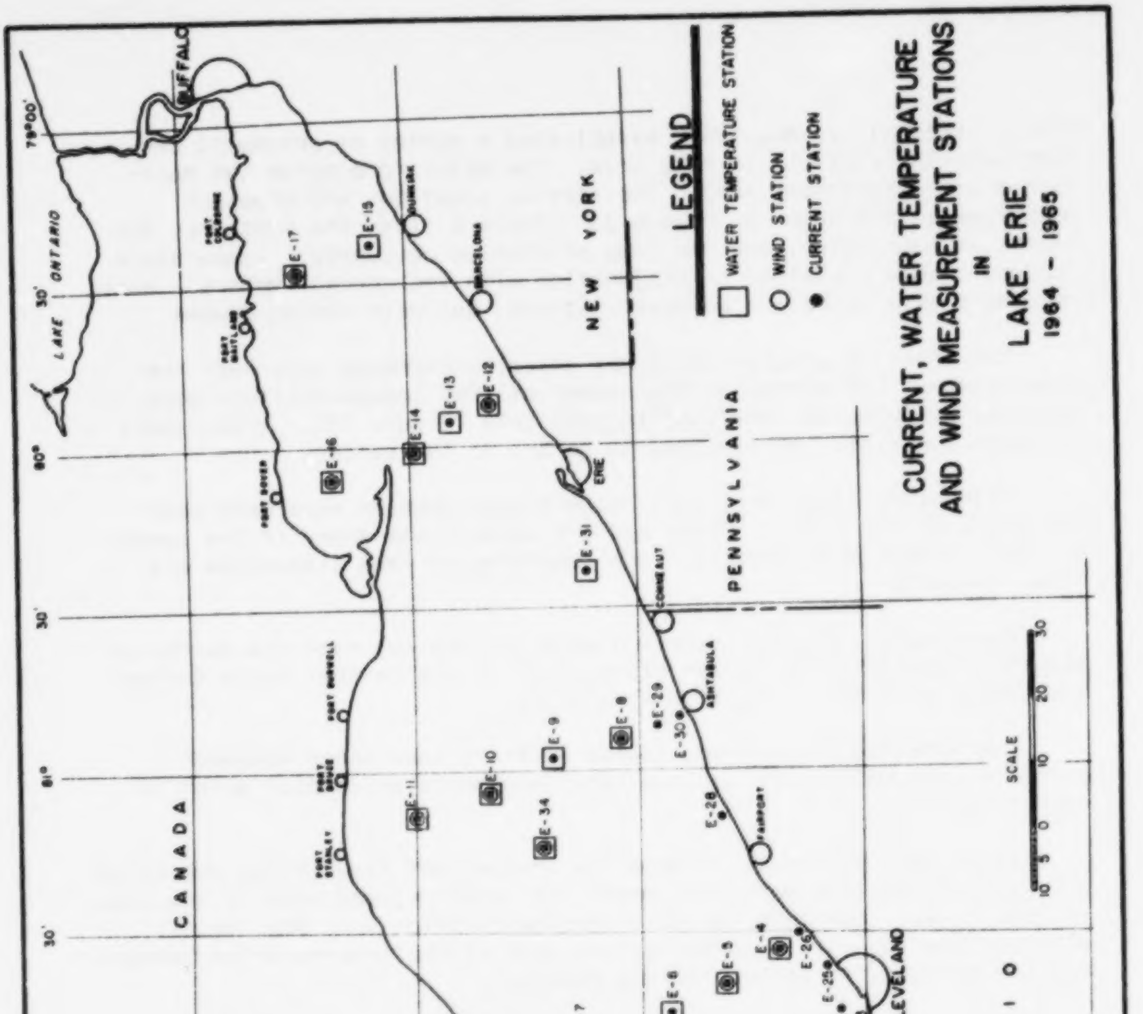
The metering program and seabed drifters have shown movement patterns very unlike the surface water movements which must exist in Lake Erie.

It is very difficult to describe predominant flows three-dimensionally when directions vary with depth and location, and such is the case in Lake Erie. Therefore the following description will deal mainly with surface and bottom currents, and much of the interpolation between top and bottom will be left to the reader.

WESTERN BASIN CIRCULATION

As noted previously, the water movements of the western basin have been studied more than in any other area of Lake Erie. Combining the facts determined in all those studies, a pattern of most probable dominant summer surface currents has been compiled as shown in Figure 25. The surface currents in the western half of the western basin are dominated by the Detroit River inflow. However, in the eastern half of the basin the surface flow becomes more influenced by the prevailing southwesterly winds, and this effect produces a clockwise flow around the islands. Eddy effects along the sides of the Detroit River inflow lead to sluggish movement of surface water west of Colchester, Ontario and between Stony Point, Michigan and Toledo. These eddies tend to retain waters contained within them, leading to higher concentrations of pollutants commonly found in these areas.

The surface flow of the western basin water is often changed by


LEGEND
WATER TEMPERATURE STATION
WIND STATION
CURRENT STATION
SCALE
10 5 0 10 20 30
LAKE HURON
LAKE ONTARIO
LAKE ST. CLAIR
MICHIGAN
CANADA
NEW YORK
PENNSYLVANIA
OHIO
DETROIT
TOLEDO
CLEVELAND
BUFFALO
ERIE
MONROE
PORT CLINTON
SANDUSKY
HURON
VERMILION
LORAIN
FAIRPORT
ASHTABULA
CONNEAUT
BARCELONA
DUNKIRK
PORT COLBORNE
PORT MAITLAND
PORT DOVER
PORT BURWELL
PORT BRUCE
PORT STANLEY
ERIEAU
PORT ALMA
WHEATLEY
LEAMINGTON
KINGSVILLE
E-1
E-2
E-3
E-4
E-5
E-6
E-7
E-8
E-9
E-10
E-11
E-12
E-13
E-14
E-15
E-16
E-17
E-18
E-19
E-20
E-22
E-23
E-24
E-25
E-26
E-28
E-29
E-30
E-31
E-33
E-34
83°30'
83°
30'
82°
81°
80°
79°00'
43°00'
42°
41°
N

CURRENT, WATER TEMPERATURE AND WIND MEASUREMENT STATIONS IN LAKE ERIE 1964 - 1965

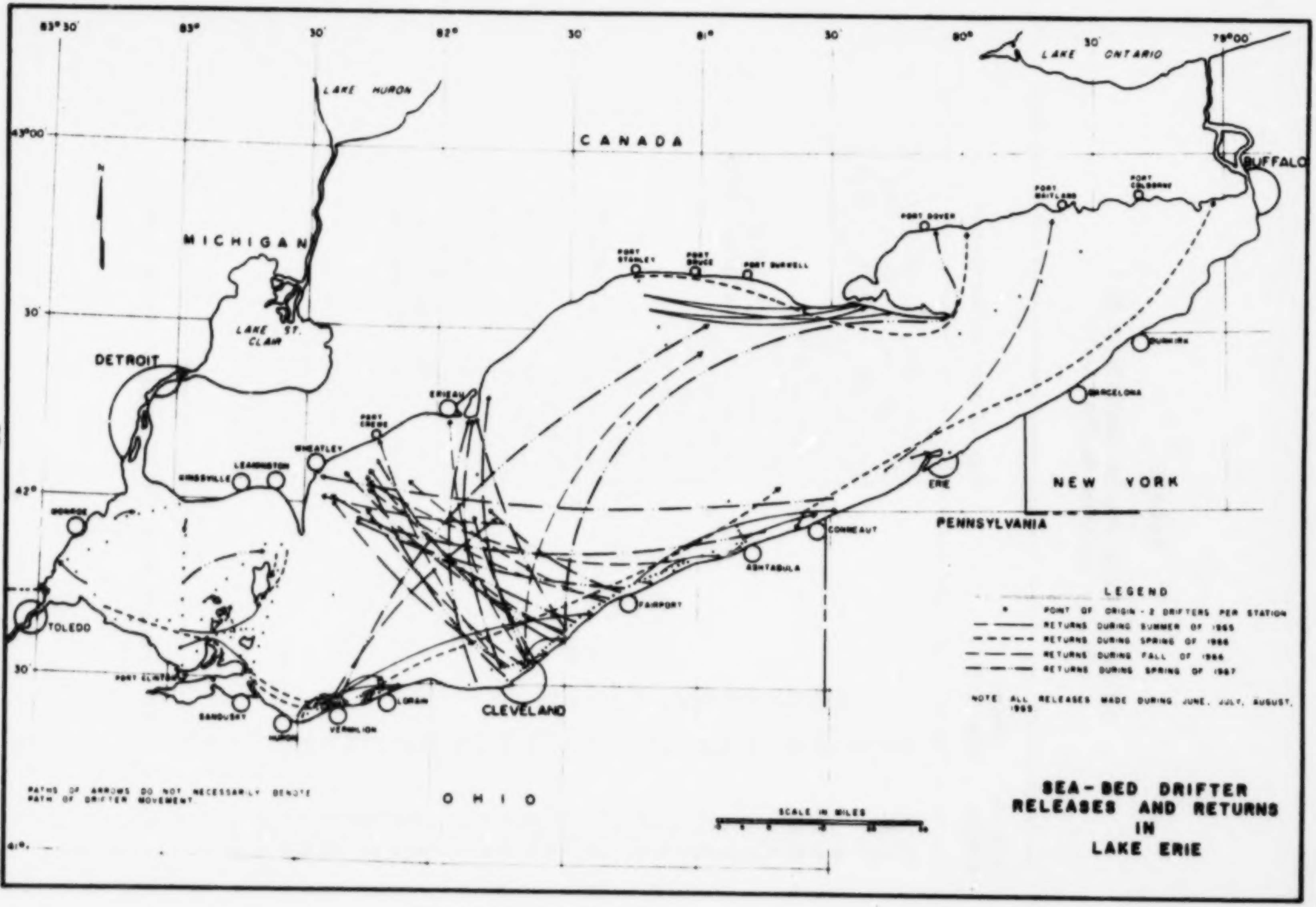
FIGURE 23

TABLE 6

CURRENT METERING STATION DESCRIPTION DATA
(station locations on Fig. 4-7)

Station Number	Meter depth (ft.)	Time of station occupancy*
E-1	30	5/18-10/12/64, 11/26/64-9/17/65
E-2	30	5/19-10/13/64, 11/26-4/20/65
E-3	30	5/19-8/6/64, 11/26/64-9/16/65
E-4	30, 50	5/19-10/11/64, 10/14/64-9/18/65
E-5	30, 50	5/19/64-5/1/65
E-6	30, 50	5/19/64-4/28/65
E-7	30, 50	5/19/64-9/17/65
E-8	30, 50	5/20-10/15/64, 5/3-9/19/65
E-9	30, 50	5/20-10/15/64, 10/16/64-5/2/65
E-10	30, 50	5/20/64-8/5/65
E-11	30, 50	5/20/64-9/17/65
E-12	30, 50, 75, 100	5/20/64-9/20/65
E-13	30, 50, 75, 100	5/20-10/15/64
E-14	30, 50, 75, 100, 185	5/20-9/20/65
E-15	30, 50, 75	5/21-10/23/64, 5/7-9/23/65
E-16	30, 50, 75	5/20-10/18/64
E-17	30, 50	5/7-9/24/65
E-18	30	6/11-8/6/64, 4/21-9/16/65
E-19	30	4/21-9/16/65
E-20	15	6/12-7/17/65, 8/11-9/17/65
E-22	15	6/12-7/17/65
E-23	15	6/12-7/17/65
E-24	15, 30	6/12-7/15/65, 8/8-9/17/65
E-25	15	6/16-7/15/65, 8/6-9/17/65
E-26	15	6/16-7/16/65
E-28	15	6/15-7/16/65
E-29	15, 30	6/14-7/15/65
E-30	15	6/14-7/15/65
E-31	15. 30, 45	6/14-7/15/65
E-33	15	4/21-9/15/65
E-34	5, 7, 9, 11, 13, 14, 16, 18, 20, 22	7/29-8/12/65

* Record length averages about 60% of total occupancy times.


83° 30'
83°
30'
82°
30'
81°
30'
80°
30'
79°00'
43°00'
30'
42°
30'
41°
LAKE HURON
LAKE ONTARIO
CANADA
MICHIGAN
LAKE ST. CLAIR
DETROIT
BUFFALO
PORT COLBORNE
PORT MAITLAND
PORT DOVER
PORT STANLEY
PORT BRUCE
PORT BURWELL
ERIEAU
PORT CREWE
WHEATLEY
LEAMINGTON
KINGSVILLE
MONROE
TOLEDO
PORT CLINTON
SANDUSKY
HURON
VERMILION
LORAIN
CLEVELAND
FAIRPORT
ASHTABULA
CONNEAUT
ERIE
BARCELONA
DUNKIRK
NEW YORK
PENNSYLVANIA
OHIO
N
SCALE IN MILES

SEA-BED DRIFTER RELEASES AND RETURNS IN LAKE ERIE

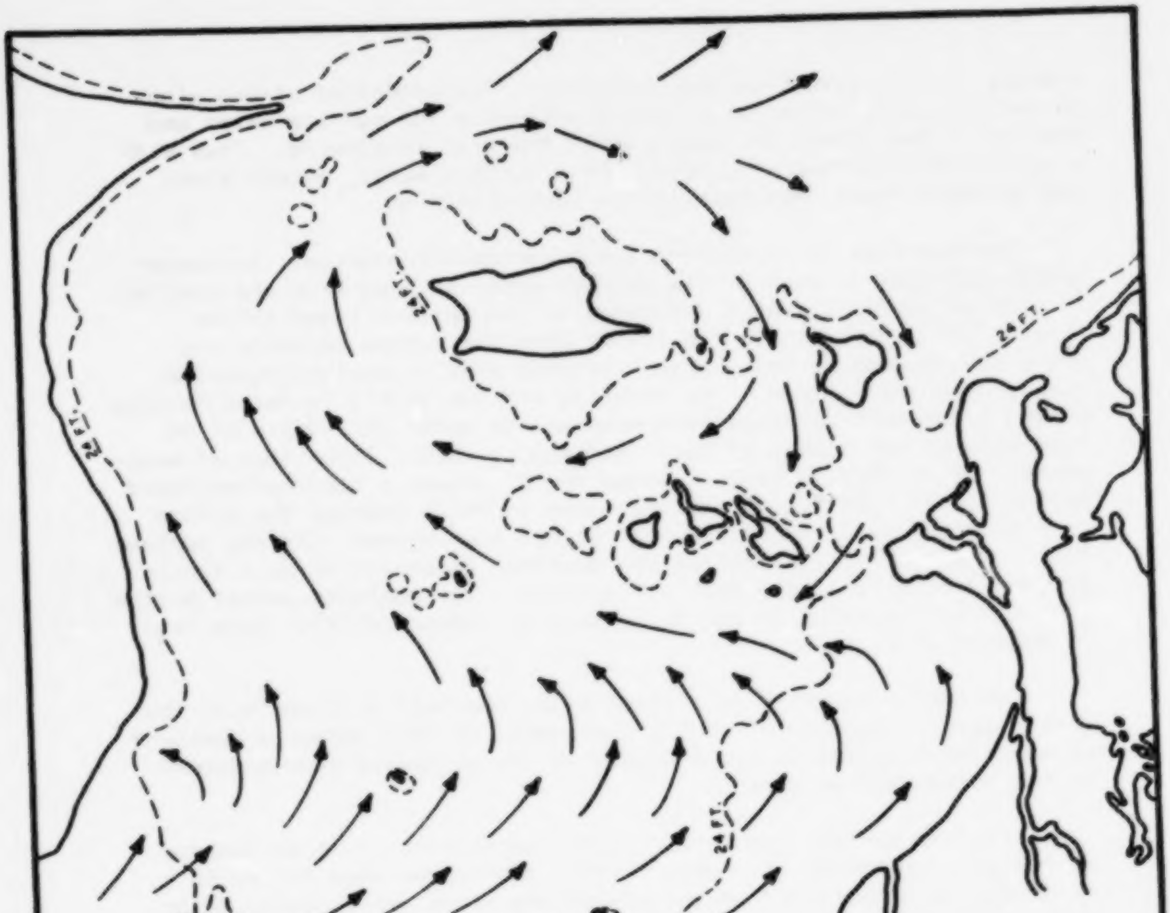
LEGEND

- • POINT OF ORIGIN - 2 DRIFTERS PER STATION
- RETURNS DURING SUMMER OF 1965
- RETURNS DURING SPRING OF 1966
- RETURNS DURING FALL OF 1966
- RETURNS DURING SPRING OF 1967

NOTE ALL RELEASES MADE DURING JUNE, JULY, AUGUST, 1965

PATHS OF ARROWS DO NOT NECESSARILY DENOTE PATH OF DRIFTER MOVEMENT.

FIGURE 24


24 FT.
24 FT.
24 FT.
24 FT.
SCALE
5
0
5
10
N

DOMINANT SUMMER SURFACE FLOW IN
LAKE ERIE - WESTERN BASIN
(DIRECTION ONLY)

FIGURE 25

changes in wind direction and intensity. The effect of strong winds on surface circulation is to essentially skim the surface water and move it in the direction toward which the wind is blowing. Thus with a sufficiently strong wind most of the surface water, except along the windward shore, may move in the same direction.

Surface flow tells nothing about bottom circulation. In summer bottom currents in much of the western basin of Lake Erie are similar to surface currents, being dominated by the Detroit River inflow (Figure 26). However, in the island area the bottom currents are often the reverse of the surface currents with a counter-clockwise flow around the islands. The metering station (E-19) in Pelee Passage showed a dominant northwestward movement of water at a depth of 30 feet between the months of April and August 1965. Three days of measurement at 30 feet in South Passage (E-18) showed a dominant eastward movement. In late August and September in Pelee Passage the bottom flow had reversed, indicating that it had then become like the surface flow. Apparently lake cooling is important in establishing a top to bottom uniformity of dominant circulation. The dominant annual bottom flow may be clockwise around Pelee Island. Seabed drifter data tend to support this.

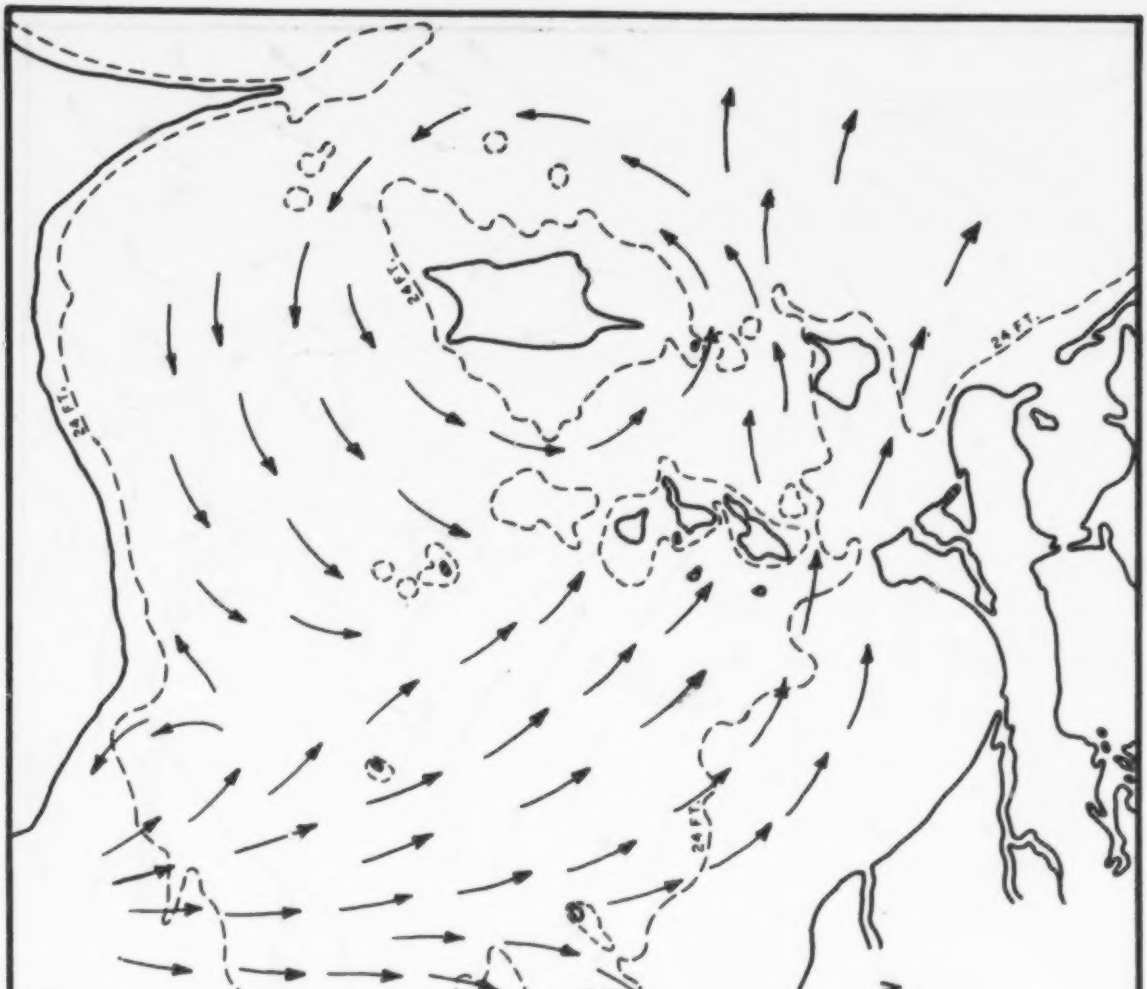
Records of currents at station E-34, one-half mile north of the Toledo water intake crib, during the summer of 1965 showed a dominant movement northwestward, compatible with the clockwise eddy movement in the Toledo-Monroe area.

Like the surface movement, bottom currents can also be changed by the wind, although it probably takes a stronger wind to create a major change of pattern. With very strong winds, which cause major changes of water level, the bottom currents are essentially the reverse of surface currents. This means, for example, that a strong westerly wind will cause bottom currents toward the west and a strong easterly wind will cause bottom currents to shift toward the east. Continuity considerations demand that subsurface reversals occur.

In the western basin water movements are not all so simple as described above. Seiches and changing winds complicate the patterns which occur at any particular time. An ice cover will enable the existence of a more or less stable pattern which should be similar to the dominant pattern of summer surface flow (Figure 25).

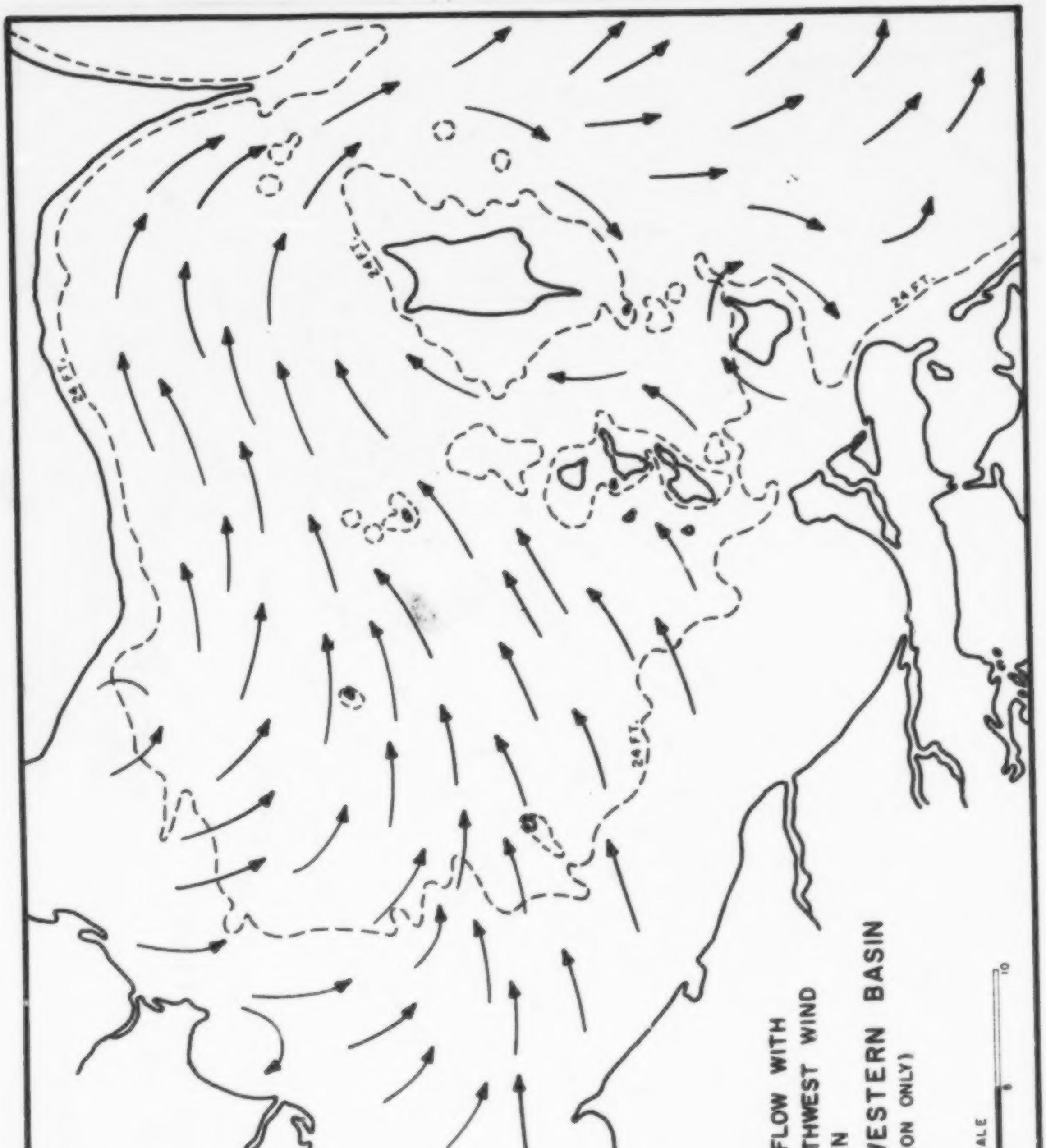
The probable surface and bottom flows under different strong wind conditions are shown in Figures 27 through 32. The western basin water apparently will show these kinds of responses year-round in the ice-free period. However, the reverse response in bottom waters apparently becomes less in fall and winter.

The most significant effects of current patterns in the western basin are:


24 FT.
24 FT.
24 FT.
24 FT.
24 FT.
SCALE
5
0
5
10
N

DOMINANT SUMMER BOTTOM FLOW
IN
LAKE ERIE - WESTERN BASIN
(DIRECTION ONLY)

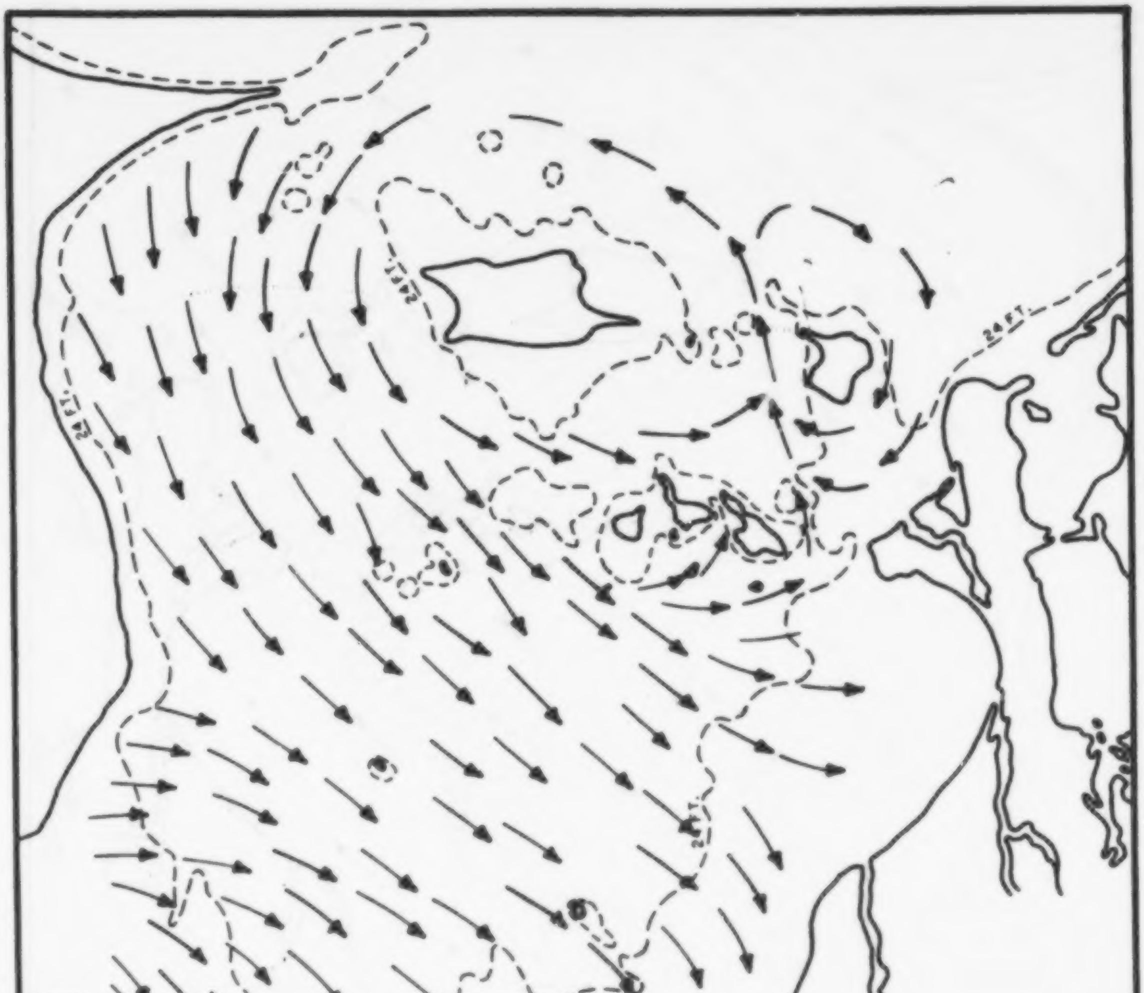
FIGURE 26



SURFACE FLOW WITH STRONG SOUTHWEST WIND IN LAKE ERIE - WESTERN BASIN (DIRECTION ONLY)

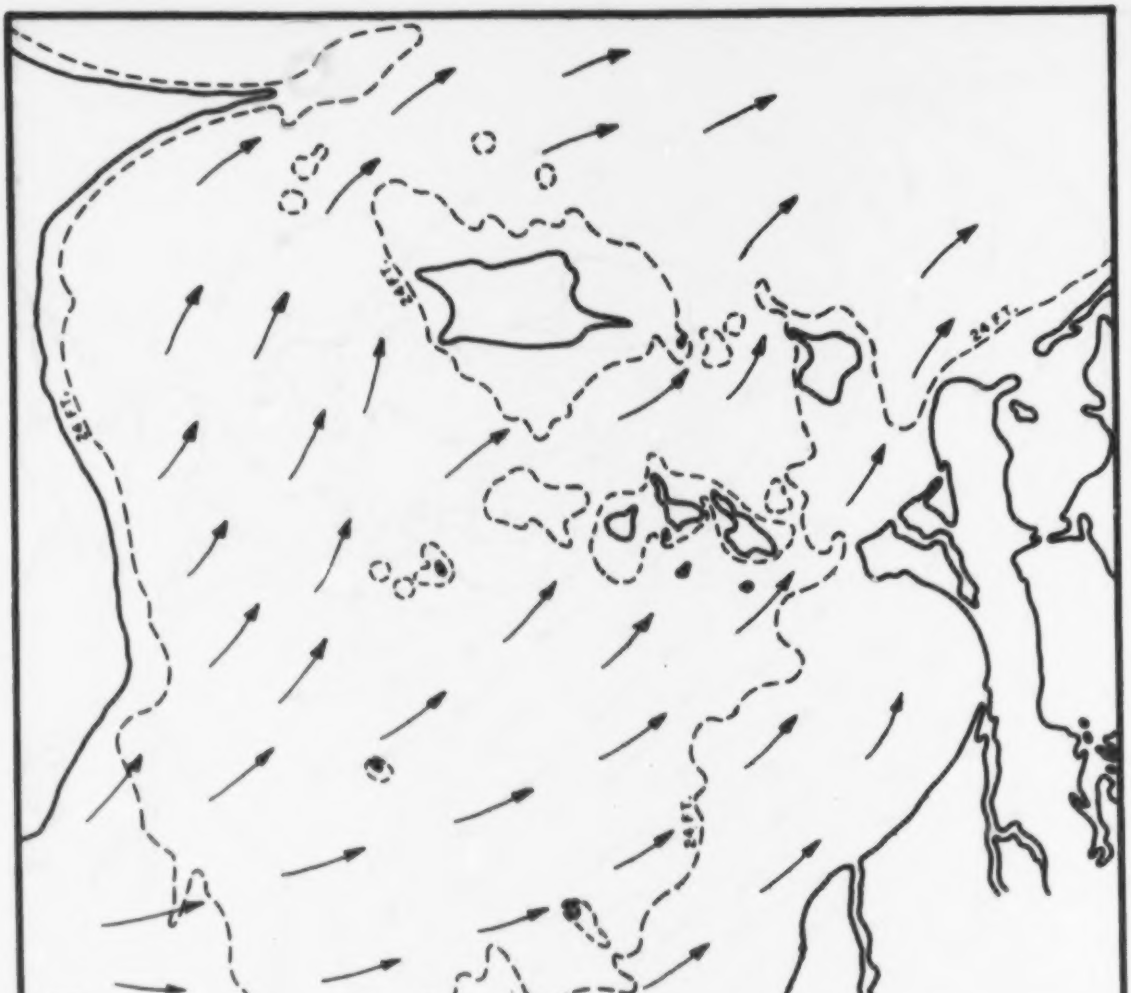
24 FT.
24 FT.
24 FT.
24 FT.
24 FT.
SCALE
5
0
5
10
N

FIGURE 27


24 FT.
24 FT.
24 FT.
24 FT.
SCALE
5
0
5
10
N

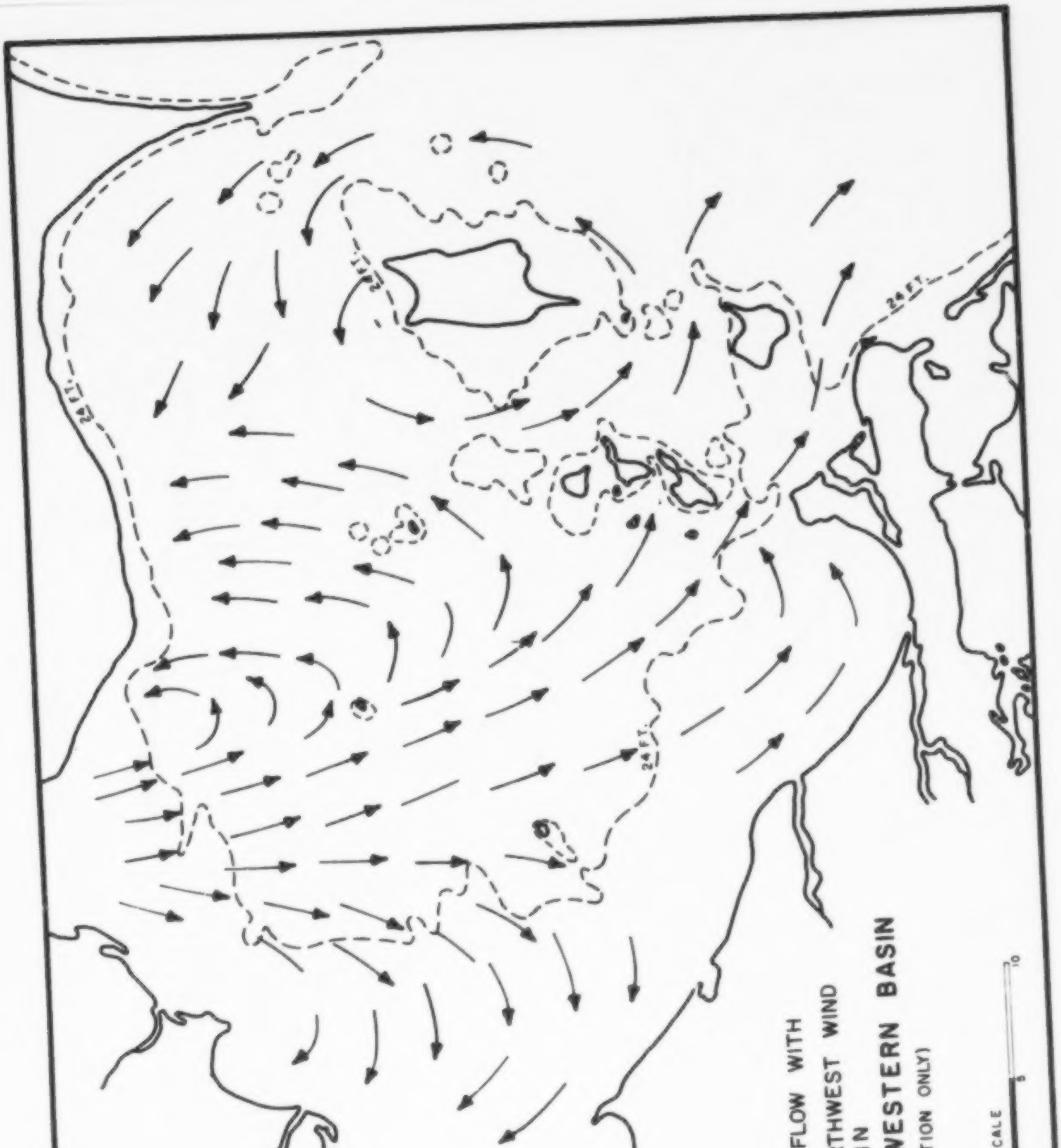
BOTTOM FLOW WITH
STRONG SOUTHWEST WIND
IN
LAKE ERIE - WESTERN BASIN
(DIRECTION ONLY)

FIGURE 28


24 FT.
24 FT.
24 FT.
24 FT.
SCALE
0
5
10
N

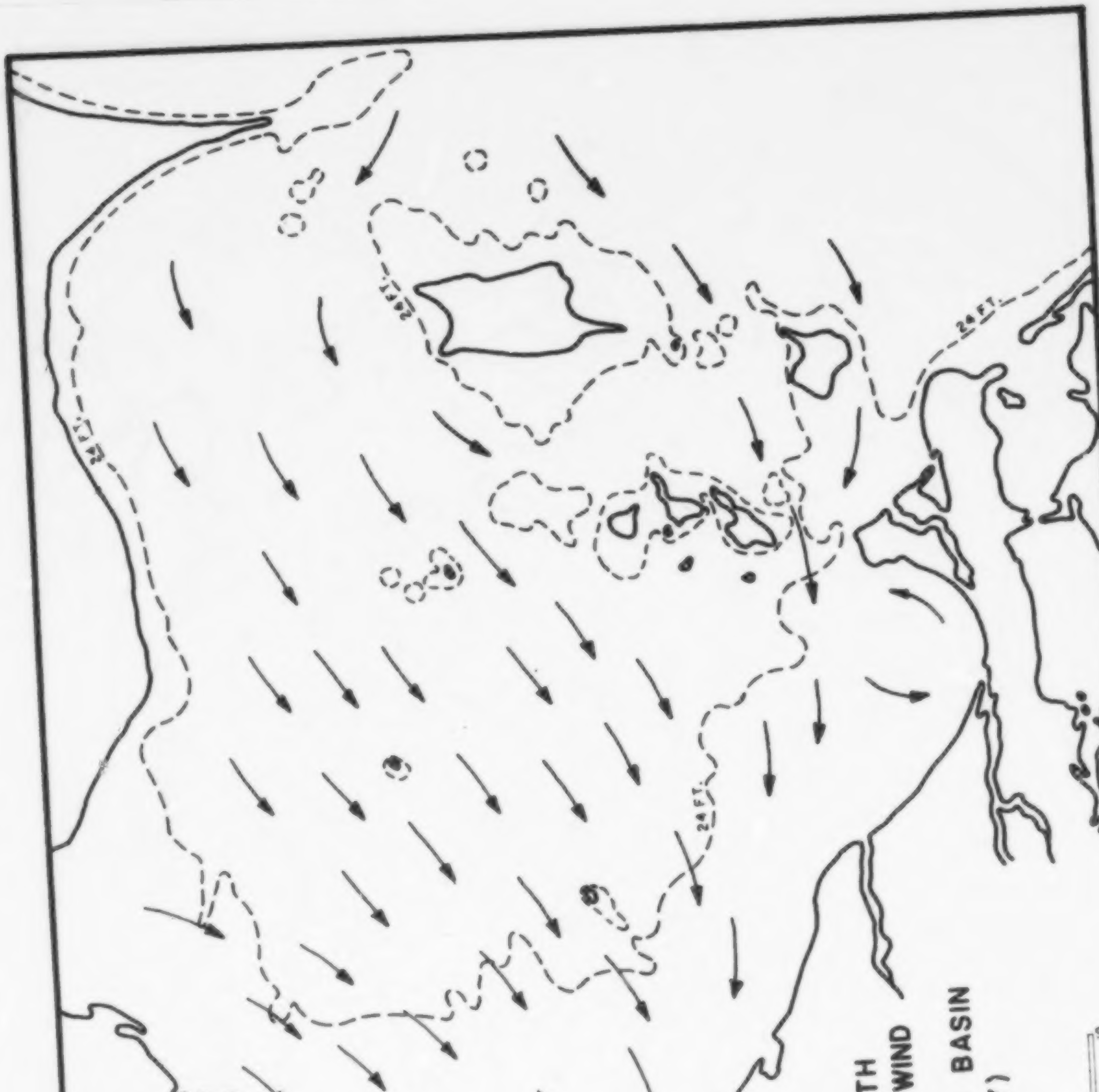
SURFACE FLOW WITH
STRONG NORTHWEST WIND
IN
LAKE ERIE - WESTERN BASIN
(DIRECTION ONLY)

FIGURE 29


24 FT.
24 FT.
24 FT.
24 FT.
SCALE
5
0
5
10
N

BOTTOM FLOW WITH
STRONG NORTHWEST WIND
IN
LAKE ERIE - WESTERN BASIN
(DIRECTION ONLY)

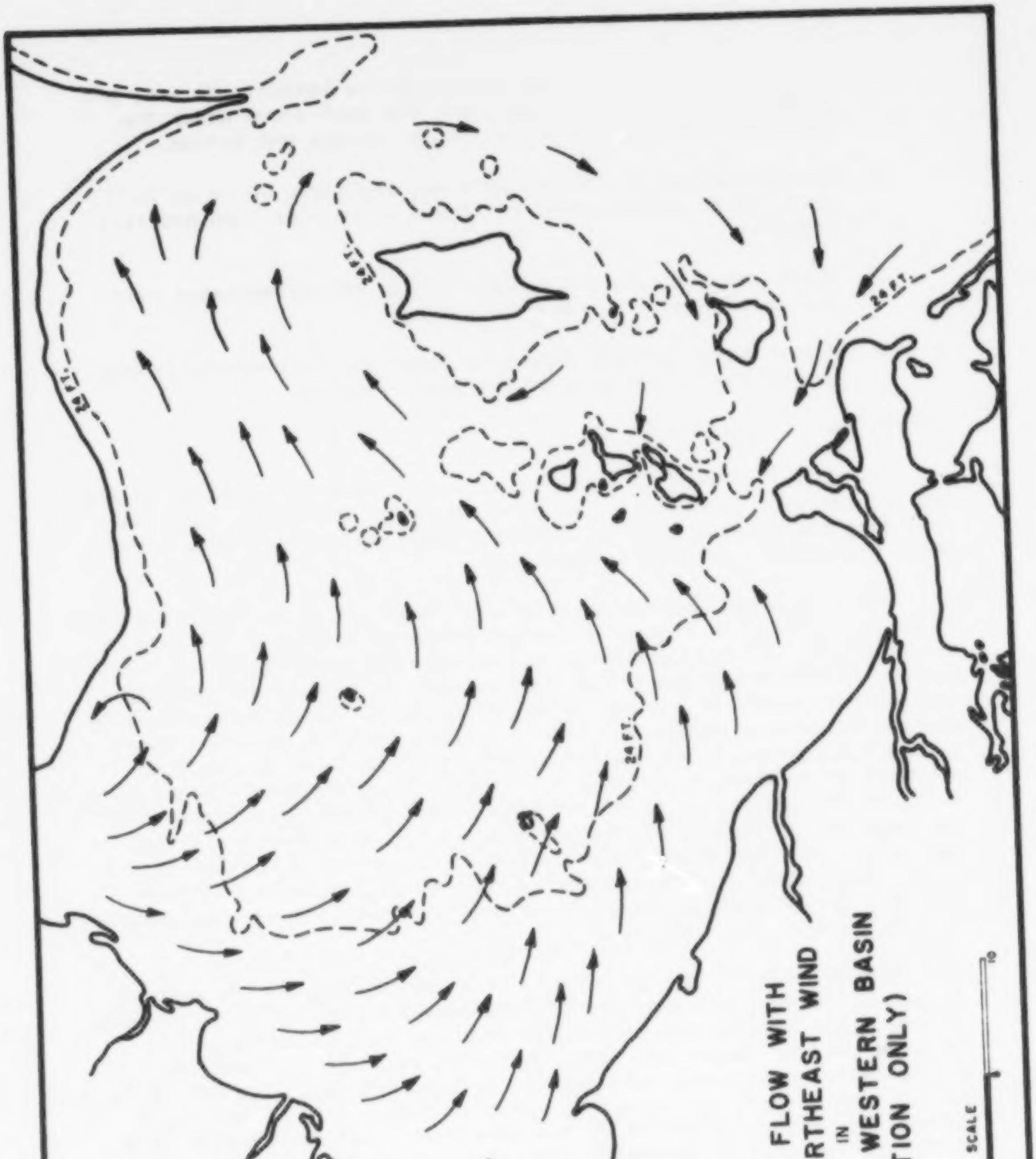
FIGURE 30



SURFACE FLOW WITH STRONG NORTHEAST WIND IN LAKE ERIE - WESTERN BASIN (DIRECTION ONLY)

24 FT.
24 FT.
24 FT.
24 FT.
SCALE
0
5
10
N

FIGURE 31


24 FT.
24 FT.
24 FT.
24 FT.
SCALE
0
5
10
N

BOTTOM FLOW WITH STRONG NORTHEAST WIND IN LAKE ERIE - WESTERN BASIN (DIRECTION ONLY)

FIGURE 32

1. Concentrations of contaminants from the Detroit, Raisin, and Maumee Rivers may build up along the west shore under the conditions of dominant flows, both surface and bottom.

2. Concentrations of contaminants may similarly build up to even higher values under ice cover since wind then has less effect.

3. Winds cause mixing and redistribution of contaminants over the entire basin in ice-free periods.

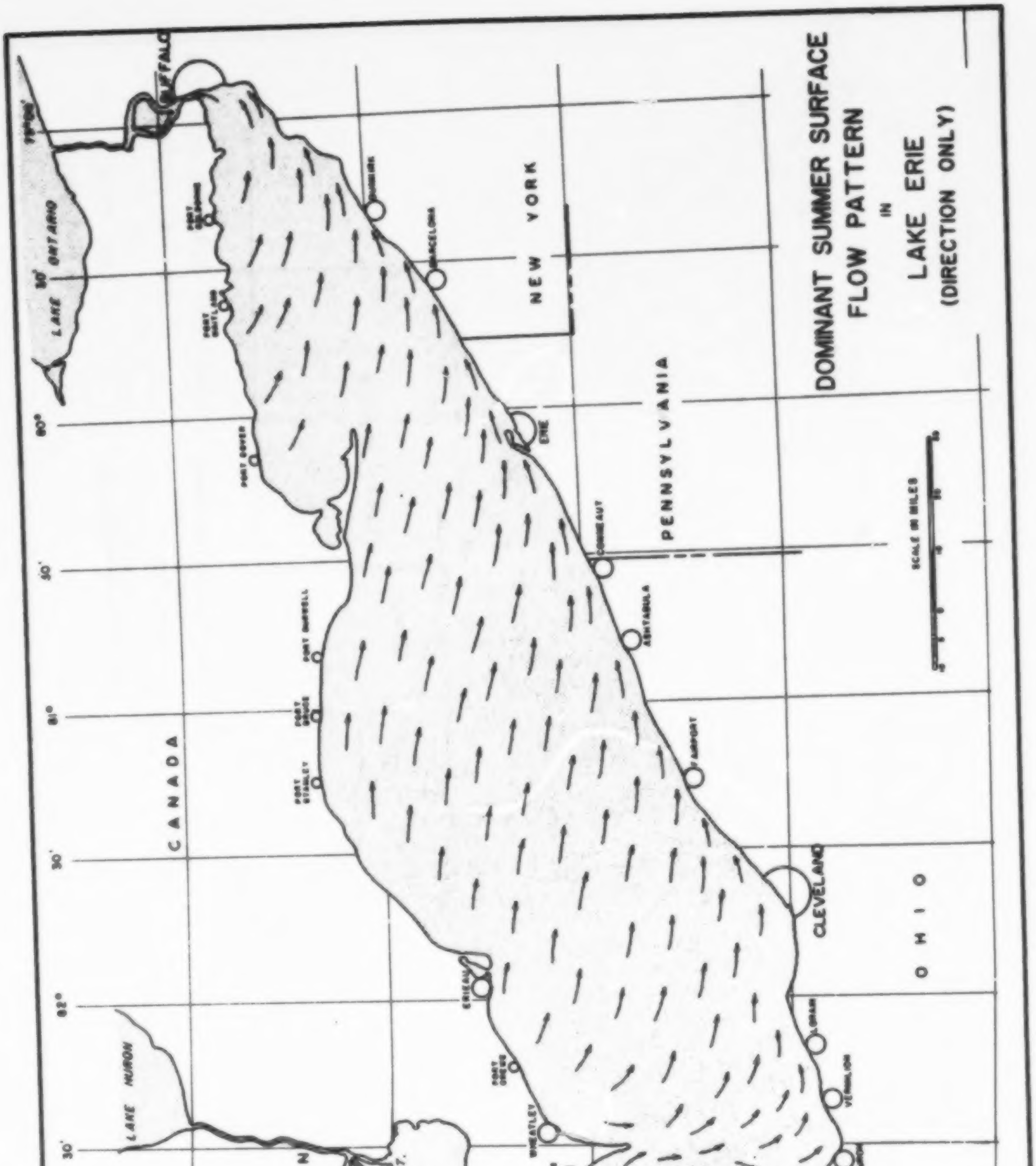
4. A portion of central Lake Erie water may recirculate in and around the island area of the western basin.

CENTRAL BASIN CIRCULATION

The effect of wind is over-riding in the water circulation of the central basin of Lake Erie. The orientation of the basin, with its long axis essentially parallel to the prevailing southwesterly winds makes this effect especially important.

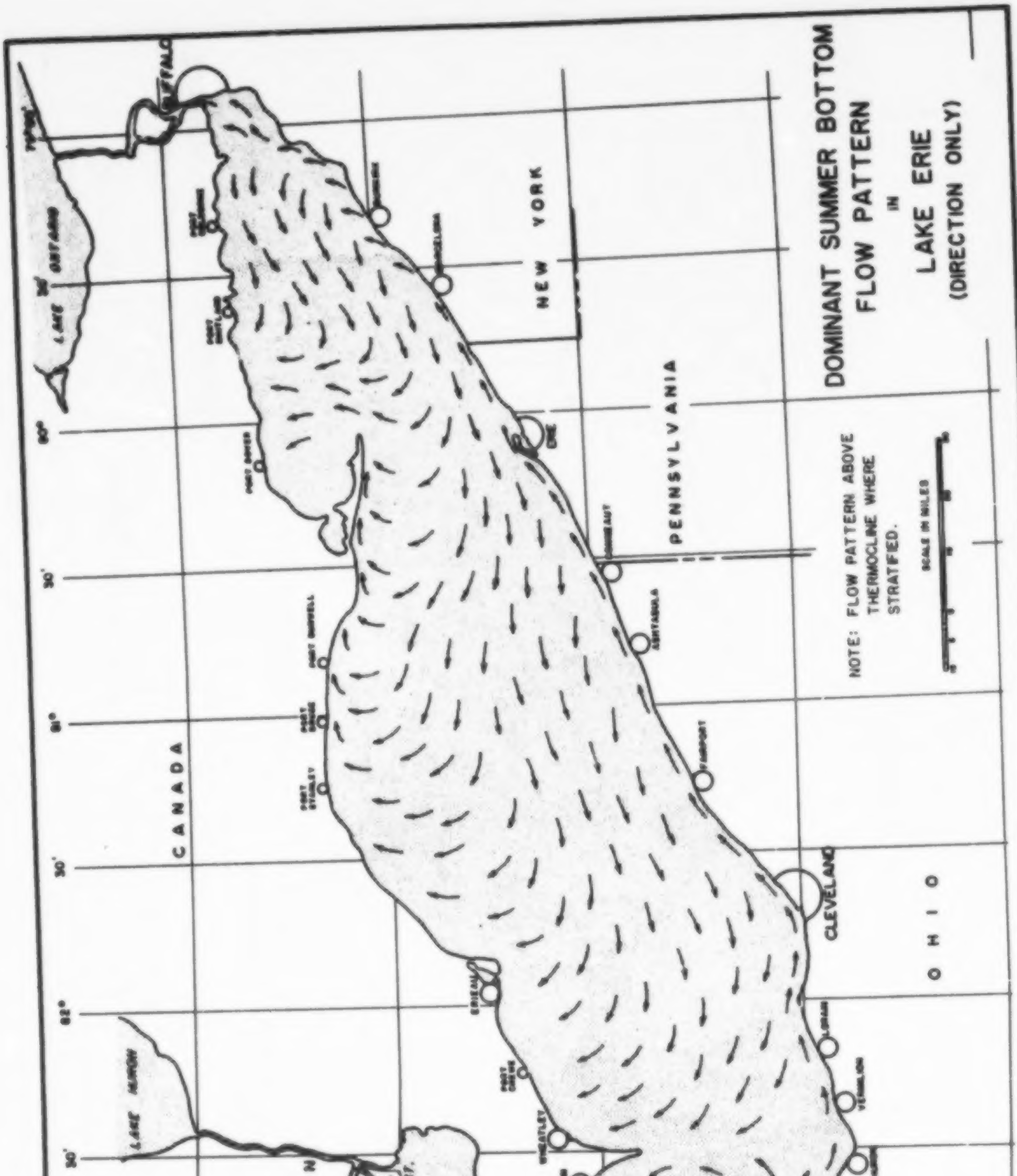
The predominant summer surface water movement in central Lake Erie is as illustrated in Figure 33, based on the results of drift card, drift bottle, and drogue studies made by several other agencies. This pattern of surface movement has been determined from investigations carried out primarily during the summer months. The pattern should be similar for winter months but with a decided shift to movement more toward the southeast and south as a result of the more frequent occurrence of northwesterly winds. It should be noted that surface currents do not exactly parallel the wind direction but move somewhat to the right of it because of the Coriolis effect. It should also be understood that the predominant pattern is essentially that of resultant movement over an extended period, and at any one time, surface movement may be greatly different or even reversed, responding quickly to wind changes.

Bottom currents in central Lake Erie are not similar to surface currents. Because surface currents are generally moving water in much greater quantity than can be removed from the basin, the balancing movement must be subsurface and essentially a return flow over most of the basin, responding less quickly to wind changes. The predominant bottom flow pattern for summer is shown in Figure 34. In this case bottom flow means the motion at the lake bottom in unstratified water, but where the lake is thermally stratified it means the predominant movement at the bottom of the epilimnion. It is this bottom flow, between 30 to 60 feet below water level, that the metering program in the central basin of Lake Erie has measured. The stations at which it was measured were E-1 through E-11 (Figure 23). Table 7 lists, in brief, examples of some of the monthly flows at these stations in terms


BUFFALO
LAKE ONTARIO
79°00'
30'
80°
30'
81°
30'
82°
30'
83°
83°30'
43°00'
30'
42°
30'
41°
PORT COLBORNE
PORT MAITLAND
PORT DOVER
PORT BURWELL
PORT BRUCE
PORT STANLEY
ERIEAU
PORT GREGG
WHEATLEY
LEAMINGTON
KINGSVILLE
CANADA
NEW YORK
DUNKIRK
BARCELONA
ERIE
PENNSYLVANIA
CONNEAUT
ASHTABULA
FAIRPORT
CLEVELAND
OHIO
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
TOLEDO
MONROE
DETROIT
MICHIGAN
LAKE ST. CLAIR
LAKE HURON
N
SCALE IN MILES

DOMINANT SUMMER SURFACE FLOW PATTERN IN LAKE ERIE (DIRECTION ONLY)

FIGURE 33


CANADA
MICHIGAN
NEW YORK
PENNSYLVANIA
OHIO
LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
BUFFALO
ERIE
CLEVELAND
DETROIT
TOLEDO
DUNKIRK
BARCELONA
CONNEAUT
ASHTABULA
FAIRPORT
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
MONROE
KINGSVILLE
LEAMINGTON
WHEATLEY
ERIEAU
PORT STANLEY
PORT BRUCE
PORT BURWELL
PORT DOVER
83°30'
42°00'
30'
42°
41°
83°
82°
81°
80°
SCALE IN MILES

DOMINANT SUMMER BOTTOM FLOW PATTERN IN LAKE ERIE (DIRECTION ONLY)

NOTE: FLOW PATTERN ABOVE THERMOCLINE WHERE STRATIFIED.

FIGURE 34

TABLE 7

CURRENT FLOWS AT CENTRAL BASIN METER STATIONS
(station locations on Figure 4-7)

Station	Depth (ft.)	June 1964			December 1964		
		Net. Dir. from	Net. Vel. cm/sec	Avg. Vel. cm/sec	Net Dir. from	Net Vel. cm/sec	Avg. Vel. cm/sec
E 1	30	118°	0.80	11.4	277°	1.41	5.6
E 2	30	--	--	--	183°	0.83	10.4
E 3	30	--	--	--	315°	1.53	10.6
E 4	50	--	--	--	257°	2.44	7.2
E 5	30	70°	4.15	8.8	--	--	--
E 6	30	141°	1.49	5.9	87°	1.86	9.8
E 7	30	225°	--	--	--	--	--
E 7	50	--	--	--	47°	0.52	6.5
E 8	30	77°	2.31	6.8	--	--	--
E 9	30	82°	1.82	10.7	--	--	--
E 11	30	112°	6.52	10.9	--	--	--

Note: To convert velocities to ft./sec. multiply by .033.

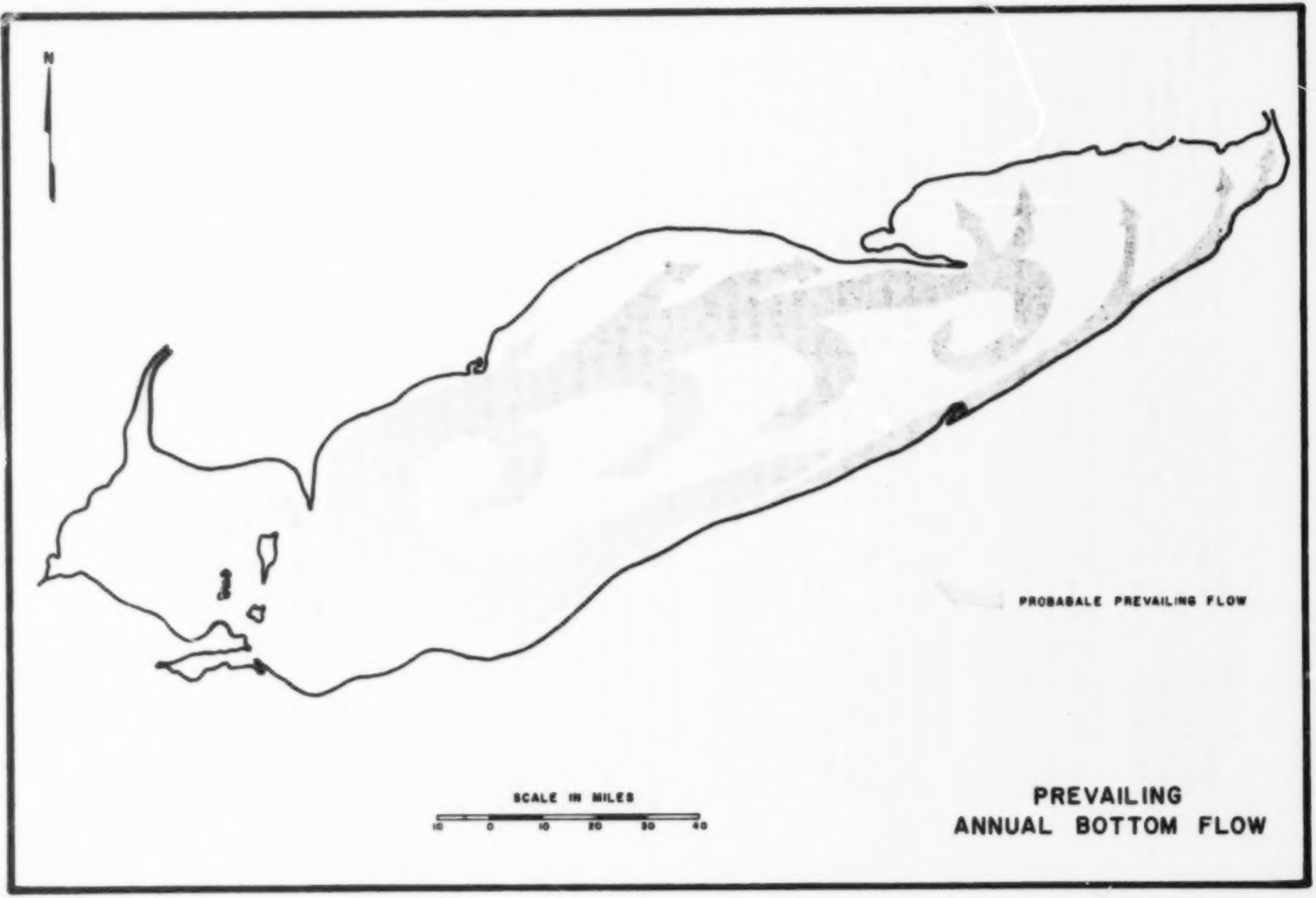
of net direction, net velocity, and average velocity of all measurements. Figure 35 based on both current meter and drifter data, shows the dominant annual bottom flow in Lake Erie. Note that this is a slightly different pattern from that of Figure 34 showing summer flow above the thermocline.

The metering program did not show, except during occasional periods of hypolimnetic upwelling, what was happening below the thermocline. There is no reason to believe that a predominant horizontal circulation pattern exists in the hypolimnion. However, high velocity currents (up to 2 ft/sec.) have been measured, during storms, in the hypolimnion. These are brought about during up and downwelling when the hypolimnion water is forced to slide around in the basin. This phenomenon becomes increasingly significant in late summer and early fall when the hypolimnion is thin and sharply divided from the epilimnion.

Bottom currents near shore are pronounced in summer and are quite different from bottom currents offshore, indicating a separate system of water movement. Seabed drifter returns from the summer of 1965 showed that (1) releases more than three miles from the south shore produced no returns, (2) releases less than three miles from shore gave many returns, (3) drifters moving westward averaged only about one mile of travel, and (4) drifters moving eastward averaged nearly 12 miles of travel. These results indicate that, especially in summer, there is a pronounced eastward movement of nearshore water (Figure 35). This has been substantiated by current meter measurements at stations E-20, E-22, E-23, E-25, E-26, and E-30 (Figure 23). Water temperature structure also supports this conclusion with a spring and summer band of warmer water near the south shore.

Dye studies along the south shore of the central basin in the summer of 1965 showed in general that surface water within the nearshore zone, while moving parallel to shore, also tended to move toward shore. This was easily noticeable when movement was toward the east. Movement toward the west at times showed a simultaneous movement away from shore but was not so pronounced.

Transport of sediments near the water line along the south shore of the central basin is not necessarily indicative of prevalent flow of water. For example, from Avon Point westward, beach sediment accretion patterns indicate a general drift toward the west. This results from wave action in the nearshore zone which is stronger from the northeast. Sediments are moved toward the west during the intermittent periods of northeasters. The slower but much more prevalent water motion toward the east is unable to transport the sediments. From Avon Point eastward the nearshore sediment drift is toward the east, the same as prevailing water flow, because increased westerly fetch makes waves from that direction more effective.


N
PROBABALE PREVAILING FLOW
SCALE IN MILES
10
0
10
20
30
40

PREVAILING
ANNUAL BOTTOM FLOW

FIGURE 35

A different type of situation exists along the north shore of the central basin. The zone of separate nearshore flow is limited in summer, if it exists at all. Temperatures indicate that the nearshore water is cooler throughout the summer than along the south shore. This implies removal of warm water and replenishment by lower waters.

Summer current metering data at stations E-7 and E-11 (Figure 23) show net motion from the south-southwest toward the Canadian shore of water at depths of 30 feet and below. Seabed drifters released off Port Stanley as far as nine miles offshore turned up on the beach far to the east. These also indicate a bottom water movement toward shore and to the east.

The Canadian shore of the central basin is more irregular than the south shore and the irregularity has a pronounced effect on wave action and beach drift along the shore. On the east side of Pelee Point the drift is toward the south-southwest, moving sediment to the tip of Pelee Point. Between Wheatley and Erieau, Ontario, the drift reverses and at Erieau it is toward the east. Along the eastern side of Pointe Aux Pins the drift is toward the south. Eastward the drift reverses again and at Port Stanley and eastward the drift is strongly toward the east. All of these drift phenomena are functions of wind and fetch and resulting wave force in the nearshore zone and are not necessarily reflecting prevailing nearshore water movement.

The most significant change in circulation in the central basin water in fall and winter is the disruption of the confining influences of water temperatures. Usually in September the surface waters of Lake Erie become nearly isothermal and by the first of October the thermocline has disappeared from the central basin. The higher temperatures which previously existed along the south shore disappear and there is no longer a density restriction to water movement. In effect then, the nearshore flow is more free to move water lakeward and cooler tributary water can under-run lake water. The bottom flow return circulation in mid-lake reaches to the lake bottom where the thermal barrier (thermocline) previously separated it from the lake bottom.

Seabed drifters tend to confirm a radical change in lake circulation in late fall. Many of the drifters released in the central basin near the south shore in the early summer of 1965 reappeared in the fall of 1966 and the spring and fall of 1967. There were no returns of consequence in the fall of 1965 and the summers of 1966 and 1967. The fall 1966 and later returns were unexpected but the consistency of the returns pattern in both space and time indicates that most of the drifters were probably carried across the lake and re-transported during high velocity northerly and westerly winds. The probability of nearshore water crossing the lake along the bottom has been shown and it is likely that this is common in fall and winter.

In spring when the shore water warms to several degrees above the temperature of mid-lake water, the south shore nearshore flow zone is reestablished. A "thermal bar" (Rogers, 1965) may be created shortly after the spring thaw and warmer tributary discharges may be even more confined to the nearshore zone. This condition can exist only when a 4°C isotherm exists with colder water on one side and warmer on the other.

Along the northern shore in fall and winter the water movement probably is not greatly different than in summer, but supporting data are lacking.

Drogue studies near shore, off western Cleveland in August 1964 showed that a dense pattern of drogues resulted in little dispersion, indicating that dispersion of inputs may be slow.

Conclusions which can be made regarding the pollutional aspects of currents in central Lake Erie are as follows:

1. Tributary and lake outfall discharges in spring and summer along the south shore tend to stay near shore and move eastward primarily as a result of the prevailing southwesterly winds.

2. In fall and early winter the same kinds of discharges can under-run the lake water and be distributed over the basin.

3. Contaminants reaching more than three miles off shore are likely to be distributed over the entire basin.

4. A vertical circulation in mid-lake exists year-round with easterly surface flow and westerly moving bottom flow.

5. The hypolimnion of mid-summer does not have a net circulation flow but does have occasional high-velocity flow as a result of up and downwelling. This flow is capable of resuspending bottom sediments.

6. Surface waters in summer move toward the south shore and away from the north shore.

7. Velocities at any level can be up to 2 feet per second during storms.

8. Vertical turbulent mixing is very effective in storms.

9. Dispersion is slow and limited horizontally.

EASTERN BASIN CIRCULATION

Water circulation in the eastern basin is also primarily wind-controlled. Flow-through currents become important near the headwaters of the Niagara River but otherwise are insignificant.

The surface water movement in the eastern basin appears to be similar to that of the central basin in that the dominant flow is eastward and toward the south shore (Figure 33). The predominant surface flow over most of the eastern basin is probably similar throughout the year but with a shift more toward the south in fall and winter.

The surface flow in the nearshore zone along the south shore is predominantly to the east, but an essentially independent summer zone such as in the central basin is not a persistent feature and is probably most important in spring and early summer.

Subsurface flow in summer, according to current meter measurement, is somewhat confused at and above the thermocline. It appears to be predominantly toward the west at stations E-12, E-15, and E-17, but toward the east at E-14 and toward the northwest at E-16 (Figure 23). The resulting areal pattern is apparently as shown in Figure 34 for the bottom of the epilimnion in stratified water. This pattern is often disrupted and confused by commonly occurring internal thermoclinal waves. Below the thermocline another system of circulation exists. Just below the thermocline the predominant motion is apparently similar to that just above the thermocline. It appears that a vertical circulation may be important in the hypolimnion and that the lake bottom currents are near the reverse of currents just below the thermocline with a horizontal clockwise motion superimposed. Velocities at the bottom are ordinarily very slow however, increasing upward. Upwelling in the eastern basin does not cause high-velocity currents as it does in the central basin.

The thermocline disappears in the eastern basin ordinarily in November. The circulation changes to one system with a predominant southeastward moving surface flow and a westward moving current at the lake bottom again with a clockwise bottom flow superimposed. Velocities decrease with depth and are probably insignificant at the bottom except within a few miles of shore in shallower waters. The assumed annual prevailing flow at the bottom is shown in Figure 35.

In summary the eastern basin circulation is similar to the central basin and in general is as follows:

1. A vertical circulation exists above the thermocline in summer, dominantly eastward at the surface and westward in the lower part of the epilimnion.

2. A vertical circulation, similar to above, exists, top to bottom in early winter and perhaps all winter with very slow movement at the bottom in deeper water.

3. Internal waves on the thermocline lead to turbulent mixing in the epilimnion and cause currents in haphazard directions.

4. Discharges from tributaries are carried to deep water quickly at nearly all times of the year and a separate nearshore current is limited to spring and early summer.

5. Discharges not caught in the Niagara outflow can be distributed over the entire basin.

6. Surface water moves toward the south shore and away from the north shore and vice versa at depth.

7. Discharges into upper waters of either the central and eastern basins may at one time or another be found nearly anywhere in either of these basins.

8. Water below the level reached by the summer thermocline may be trapped there for long periods, on the order of a year or more.

GENERAL OBSERVATIONS

During periods of quiet weather, rotational currents, related to the inertial period and internal waves, are created in the central and eastern basins with no net transport involved. These are particularly evident in summer, becoming rather rare in winter.

It appears that, at least in summer, the bulk of the drainage from Lake Erie is from surface water, much of which has been moved to, and is moving along the south shore of the central and eastern basins. This tends to create two retention systems, one of which (south shore) is much shorter than the theoretical detention time, and one which is much longer (mid-lake).

CHAPTER 3

LAKE ERIE CHEMICAL CHARACTERISTICS

SEDIMENT CHEMISTRY

In order to gain some knowledge of the composition of lake bottom sediments, 16 samples from the western basin, 21 from the central basin, and 23 from the eastern basin were analyzed for the following constituents:

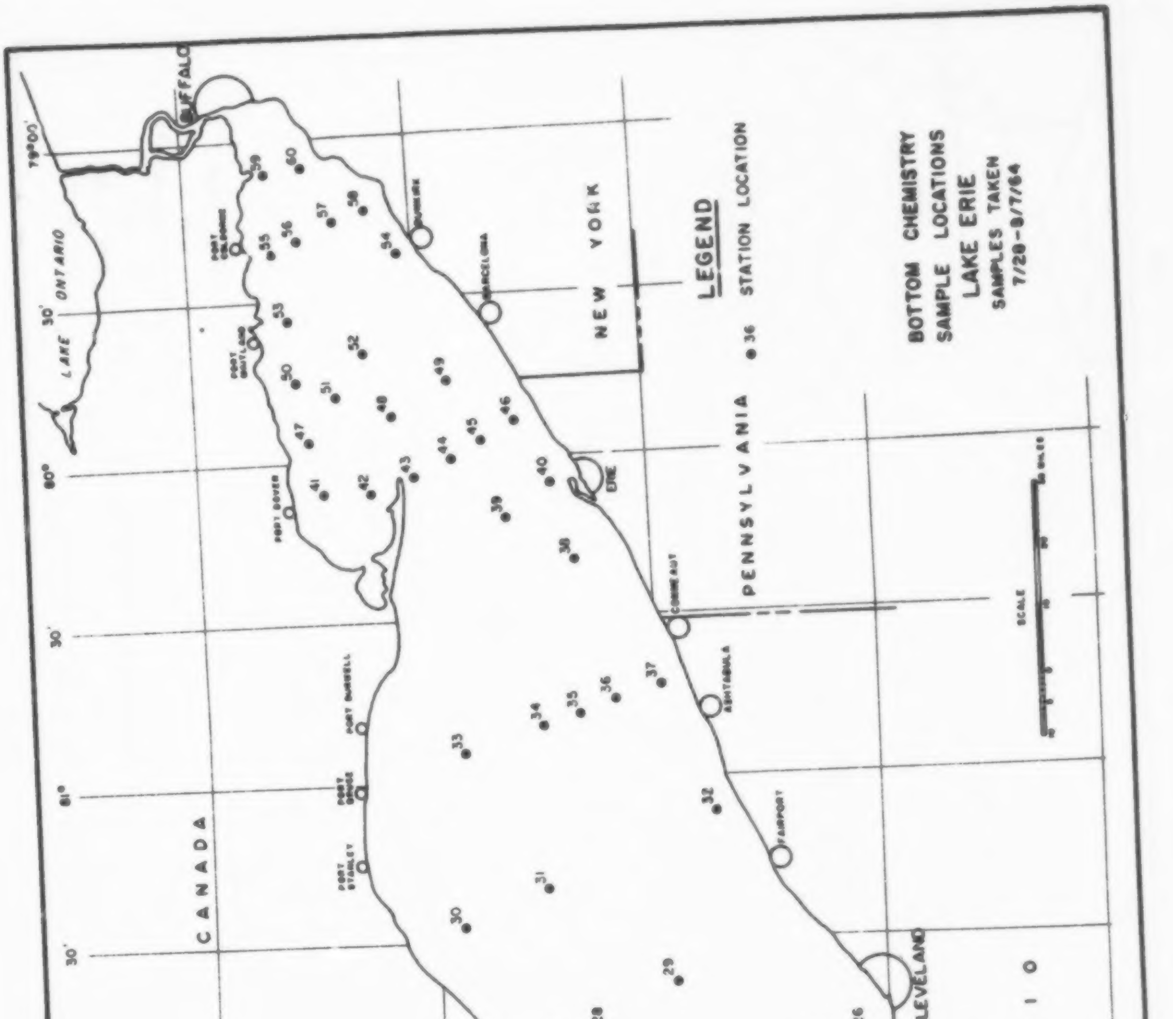
a. Total iron
b. Total phosphate
c. Sulfide
d. Ammonia nitrogen
e. Nitrate and nitrite nitrogen
f. Organic nitrogen
g. Volatile solids
h. Chemical oxygen demand

The samples were taken between July 28 and August 7, 1964. Sampling and analyses were not of sufficient density (Figure 36) to provide more than generalities as to areal extent of concentration ranges.

The results of bottom sediment analyses are presented to show the existence of substances and their abundance in each basin. The results are listed in Table 8 for the western basin, Table 9 for the central basin, and Table 10 for the eastern basin. The results are reported as milligrams per gram of sediment, oven dry weight. The data cannot be used to show rates of accumulation since the rates of sedimentation are not known.

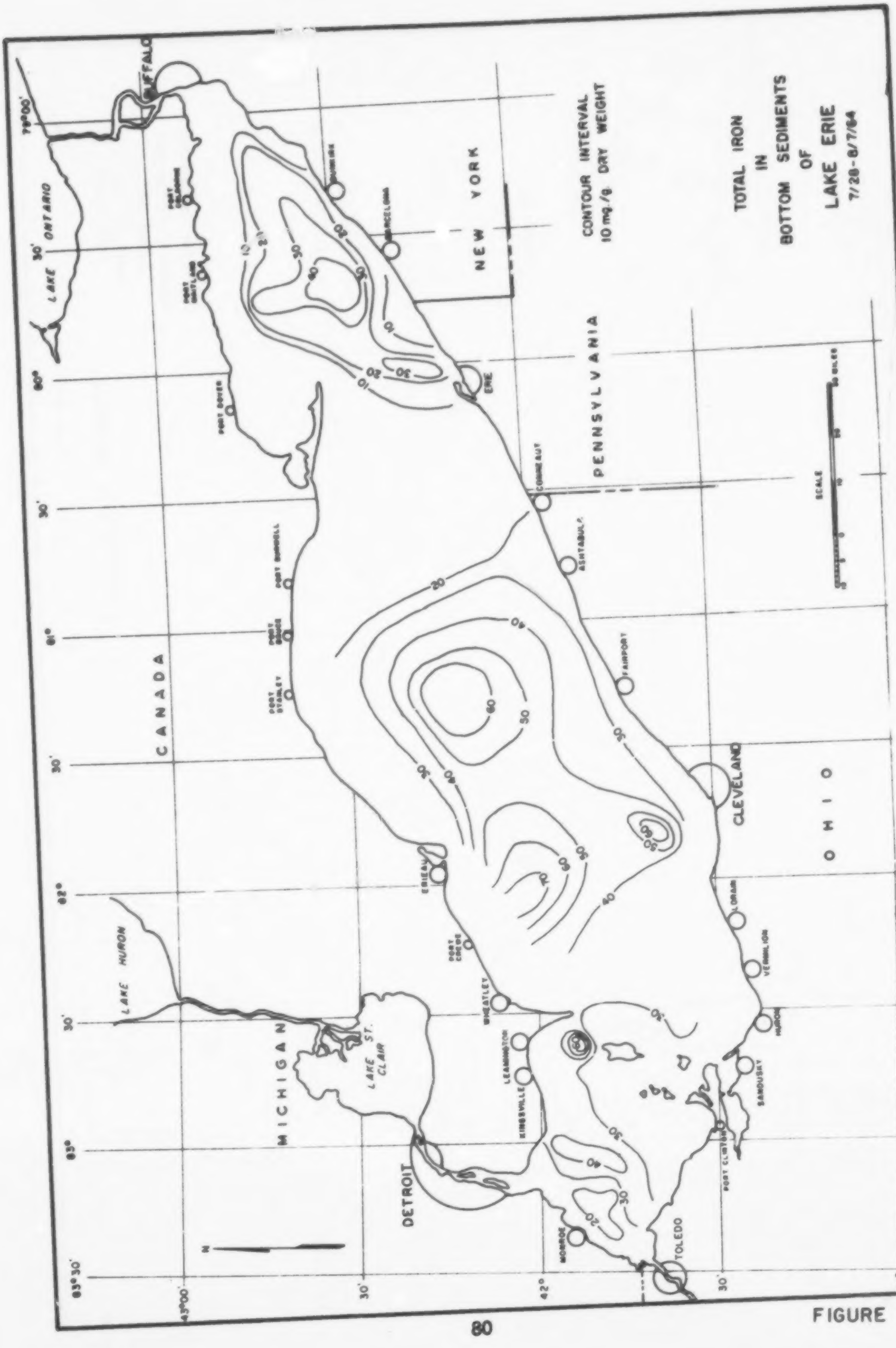
TOTAL IRON

Total iron in the bottom sediments is similar in concentration in the western and central basins, averaging 33 to 35 mg/g. The concentration drops in the eastern basin to an average of 27 mg/g. To minimize the effects of erosion, total iron averages in the central and eastern basin were calculated from samples obtained from depths greater than 10 fathoms. Sources of iron in lake sediments are glacial deposits, soluble and colloidal inputs from basin tributaries, and from Corps of Engineers dredging of navigable channels and harbors. As an example of the latter, more than 70 million pounds of iron were removed from the Cuyahoga River and Cleveland Harbor during 1967 and deposited in offshore areas. Areal patterns of iron concentration are shown in Figure 37.


LEGEND
● 36 STATION LOCATION
LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
CANADA
MICHIGAN
NEW YORK
PENNSYLVANIA
OHIO
BUFFALO
DUNKIRK
BARCELONA
ERIE
CONNEAUT
ASHTABULA
FAIRPORT
CLEVELAND
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
TOLEDO
MONROE
DETROIT
KINGSVILLE
LEAMINGTON
WHEATLEY
PORT CREWE
ERIEAU
PORT STANLEY
PORT BRUCE
PORT BURWELL
PORT DOVER
PORT MAITLAND
PORT COLBORNE
SCALE
N
79°00'
30'
80°
30'
81°
30'
82°
30'
83°
83°30'
43°00'
30'
42°
30'
41°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

BOTTOM CHEMISTRY
SAMPLE LOCATIONS
LAKE ERIE
SAMPLES TAKEN
7/28-8/7/64

FIGURE 36


CONTOUR INTERVAL
10 mg./g. DRY WEIGHT
CANADA
NEW YORK
PENNSYLVANIA
OHIO
MICHIGAN
LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
BUFFALO
DUNKIRK
BARCELONA
ERIE
CONNEAUT
ASHTABULA
FAIRPORT
CLEVELAND
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
TOLEDO
MONROE
DETROIT
KINGSVILLE
LEAMINGTON
WHEATLEY
ERIEAU
PORT STANLEY
PORT BRUCE
PORT BURWELL
PORT DOVER
PORT MAITLAND
PORT COLBORNE
79°00'
80°
81°
82°
83°
83°30'
30'
43°00'
42°
41°
N
SCALE
10
20
30
40
50
60
70

TOTAL IRON
IN
BOTTOM SEDIMENTS
OF
LAKE ERIE
7/28-8/7/64

FIGURE 37

TOTAL PHOSPHATE

The general areal pattern of total phosphate (PO_4) concentrations (divide by 3 to obtain phosphorus concentration) is shown in Figure 38. The concentrations in the bottom sediments appear to decrease somewhat from west to east. The average for the western basin samples was 2.29 mg/l while the samples from the central basin averaged 1.95 mg/l, and those from the eastern basin averaged 1.51 mg/l. Highest values were found in the western basin as expected because of large inputs of phosphates to that basin. Progressively smaller concentrations were found in the central and eastern basins due to greatly reduced inputs. Augmentation of tributary phosphate inputs occurs from sedimentation of planktonic occluded phosphorus.

Recycling of phosphates from lake sediments to overlying waters will occur during summer stratification. However, the solubilized phosphates not depleted by algal metabolism will be reprecipitated again during fall turnover.

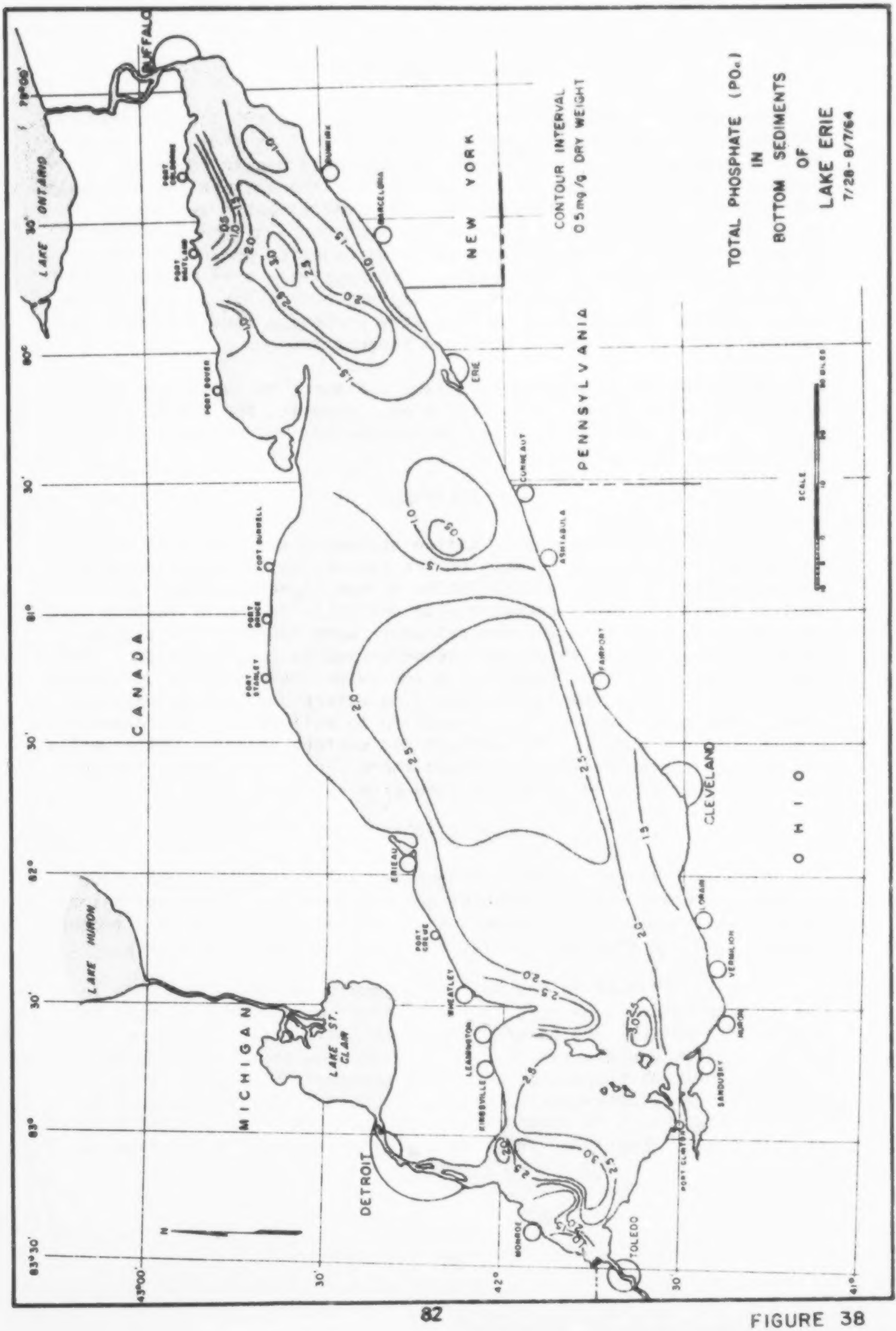
SULFIDE

Sulfide concentrations in bottom sediments averaged 0.23 mg/g in the western basin, 0.97 mg/g in the central basin, and 0.04 mg/g in the eastern basin. In addition to a much higher average, the central basin sediments showed a wide variation from 0.01 to 3.90 mg/g. The very high values in the central basin were found in the sediments below the hypolimnion which was characterized by low dissolved oxygen. The high concentrations result from low oxidation-reduction potentials exhibited by the sediments and overlying waters due to anaerobiasis. Under these conditions sulfate reduction to sulfide occurs. Anaerobiasis does not occur in the western and eastern basins. Consequently, low sulfide concentrations are found there. Figure 39 shows the general distribution of sulfides in Lake Erie sediments.

ORGANIC NITROGEN

Organic nitrogen is the nitrogen present in organic compounds. Natural nitrogen organic compounds are the result of plant and animal metabolism and decay. Relatively small amounts of synthetic nitrogen compounds may be expected to find their way to receiving waters.

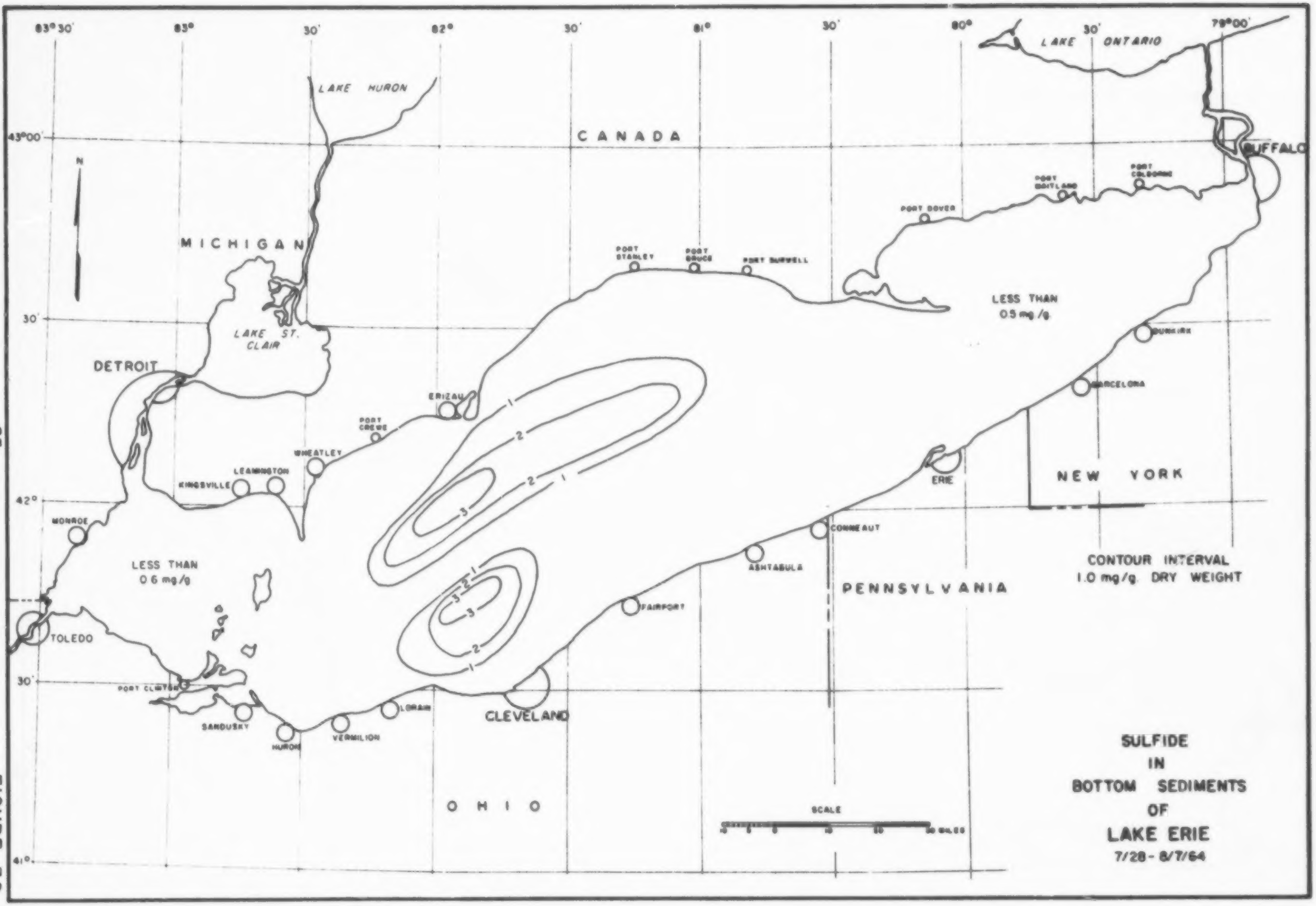
Organic nitrogen in the bottom sediments averaged 0.23 mg/g in the western basin, 1.84 mg/g in the central basin, and 0.85 mg/g in the eastern basin. The general distribution is shown in Figure 40. In the shallow western basin, with a relatively short flowthrough period, continual suspension of bottom sediments is likely, with organic nitrogen biochemically oxidized to forms readily available to aquatic life. This is substantiated by the high algal productivity of this basin. Published FWPCA data show prevailing bottom flow in


CANADA
MICHIGAN
NEW YORK
PENNSYLVANIA
OHIO
LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
BUFFALO
DETROIT
TOLEDO
CLEVELAND
ERIE
PORT COLBORNE
PORT MAITLAND
PORT DOVER
PORT BURWELL
PORT BRUCE
PORT STANLEY
ERIEAU
PORT ALMA
WHEATLEY
LEAMINGTON
KINGSVILLE
MONROE
PORT CLINTON
SANDUSKY
HURON
VERMILION
LORAIN
FAIRPORT
ASHTABULA
CONNEAUT
BARCELONA
DUNKIRK
SCALE
MILES
N
43°00'
30'
42°
30'
41°
83°30'
83°
30'
82°
30'
81°
30'
80°
30'
79°00'
0.5
1.0
1.5
2.0
2.5
3.0

CONTOUR INTERVAL
0.5 mg/g DRY WEIGHT

TOTAL PHOSPHATE (PO₄)
IN
BOTTOM SEDIMENTS
OF
LAKE ERIE
7/28 - 8/7/64

FIGURE 38


83°30'
83°
30'
82°
30'
81°
30'
80°
30'
79°00'
43°00'
30'
42°
30'
41°
LAKE HURON
LAKE ONTARIO
CANADA
MICHIGAN
LAKE ST. CLAIR
DETROIT
BUFFALO
PORT COLBORNE
PORT MAITLAND
PORT DOVER
PORT STANLEY
PORT BRUCE
PORT BURWELL
LESS THAN 0.5 mg./g.
DUNKIRK
BARCELONA
NEW YORK
ERIE
ERIEAU
PORT CREWE
WHEATLEY
LEAMINGTON
KINGSVILLE
MONROE
LESS THAN 0.6 mg/g
TOLEDO
PORT CLINTON
SANDUSKY
HURON
VERMILION
LORAIN
CLEVELAND
FAIRPORT
ASHTABULA
CONNEAUT
PENNSYLVANIA
OHIO
1
2
3
N
SCALE
CONTOUR INTERVAL 1.0 mg./g. DRY WEIGHT

SULFIDE
IN
BOTTOM SEDIMENTS
OF
LAKE ERIE
7/28 - 8/7/64

FIGURE 39

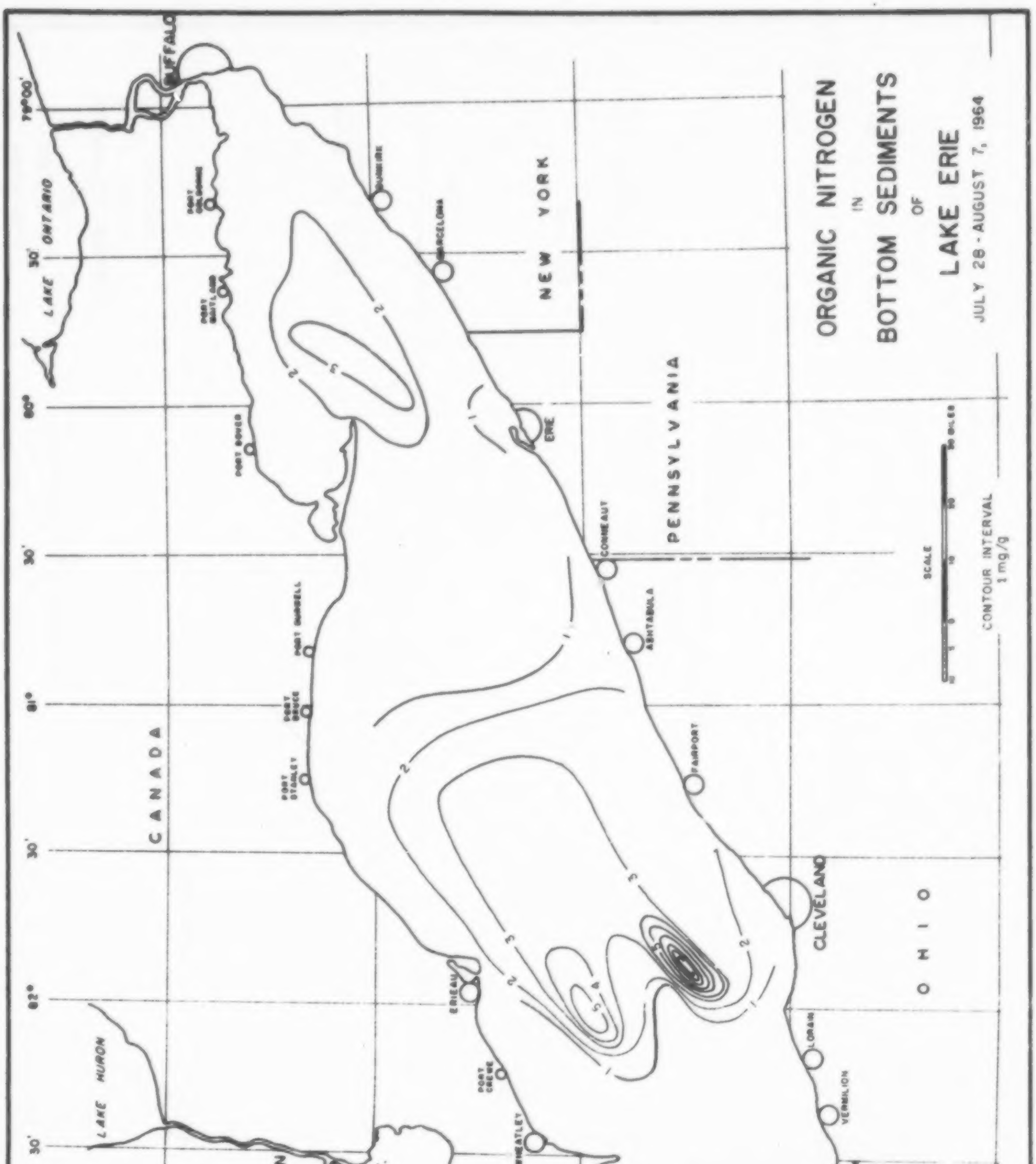
ORGANIC NITROGEN
IN
BOTTOM SEDIMENTS
OF
LAKE ERIE
JULY 28 - AUGUST 7, 1964
LAKE ONTARIO
BUFFALO
PORT COLBORNE
PORT MAITLAND
DUNKIRK
BARCELONA
NEW YORK
PORT DOVER
ERIE
PENNSYLVANIA
CONNEAUT
ASHTABULA
PORT BURWELL
PORT BRUCE
PORT STANLEY
CANADA
FAIRPORT
CLEVELAND
OHIO
ERIEAU
PORT CREWE
LORAIN
VERMILION
HURON
SANDUSKY
WHEATLEY
LEAMINGTON
KINGSVILLE
PORT CLINTON
LAKE HURON
MICHIGAN
LAKE ST. CLAIR
DETROIT
LESS THAN 0.4 mg/g
MONROE
TOLEDO
N
SCALE
CONTOUR INTERVAL 1 mg/g
1
2
3
4
5
79°00'
30'
80°
81°
82°
83°
83°30'
43°00'
42°
41°

FIGURE 40

the central basin to be extensively circulatory (Figure 35). It is indicated that a buildup of organic materials will occur as a result of the recirculation and the relatively long flowthrough period. The eastern basin with an intermediate flowthrough period, low tributary waste input and consequent low algal productivity has an average organic nitrogen concentration intermediate with respect to the other basins.

AMMONIA NITROGEN

Ammonia nitrogen, an end product in the degradation of proteinaceous materials, decreased somewhat from west to east in Lake Erie (Figure 41). The western basin sediment samples averaged 0.19 mg/g, the central basin 0.09 mg/g, and the eastern basin samples 0.07 mg/g. Ammonia is 45.2 percent of the total nitrogen in the western basin, 4.7 percent in the central, and 7.6 percent in the western. A much higher organic matter degradation rate is indicated in the western basin due to higher water temperatures.

NITRITE AND NITRATE NITROGEN

In the nitrogen cycle, organic nitrogen is gradually converted to ammonia nitrogen. Under aerobic conditions, the oxidation of ammonia to nitrites and nitrates then occurs. Lake Erie nitrate-nitrite concentrations in bottom sediments are very low since upon oxidation these forms are quickly solubilized in overlying waters. The concentration of nitrite-nitrate increased west to east in Lake Erie bottom sediments during the survey. An explanation is that sediments are less disturbed toward the east, allowing a greater opportunity for retention of these substances in the oxidation microzone through the mechanisms of adsorption. The average concentration in the samples was .001 mg/g in the western basin, .002 mg/g in the central basin, and .004 mg/g in the eastern basin.

VOLATILE SOLIDS

Volatile solids are shown as mg/g in Tables 8, 9, and 10, and the general areal pattern is shown in Figure 42. The western basin showed the highest sample average at 234 mg/g. The central basin sample average was 214 mg/g, while the eastern basin average was comparatively low at 74 mg/g. Since organic nitrogen is relatively low, and volatile solids are high, it is indicated that a large fraction of the total volatile solids in the western basin is nonprotein in character. Published FWPCA data (1968) substantiate this in work done on chlorophyll carbon and seston.

CHEMICAL OXYGEN DEMAND

The chemical oxygen demand of the bottom sediments samples averaged

TABLE 8

BOTTOM SEDIMENT CHEMISTRY - WESTERN BASIN
mg/g

Sample Location	Total Iron	Total Phosphate	Sulfide	Ammonia Nitrogen	NO_2-NO_3 Nitrogen	Organic Nitrogen	Volatile Solids	COD
1	20	.88	.01	.04	.000	.06	56	40
2	22	2.29	.34	.33	.001	.22	125	85
3	28	2.29	.05	.29	.001	.25	252	72
4	43	2.86	.56	.13	.001	.27	308	73
5	37	3.29	.36	.37	.002	.37	543	80
6	17	1.42	.12	.07	.000	.08	56	29
7	25	2.36	.27	.20	.001	.22	137	51
8	39	3.29	.40	.33	.002	.41	365	96
9	26	2.12	.21	.18	.001	.20	297	68
10	27	1.87	.21	.15	.001	.19	196	77
11	45	3.25	.04	.24	.001	.28	451	43
12	39	2.50	.06	.16	.001	.27	262	96
13	34	2.43	.32	.15	.001	.26	298	74
14	29	2.02	.27	.08	.001	.17	135	51
15	68	2.79	.25	.19	.001	.28	253	75
16	27	1.06	.21	.12	.000	.05	17	6
Avg.	33	2.29	.23	.19	.001	.23	234	63.5

TABLE 9

BOTTOM SEDIMENT CHEMISTRY - CENTRAL BASIN
mg/g

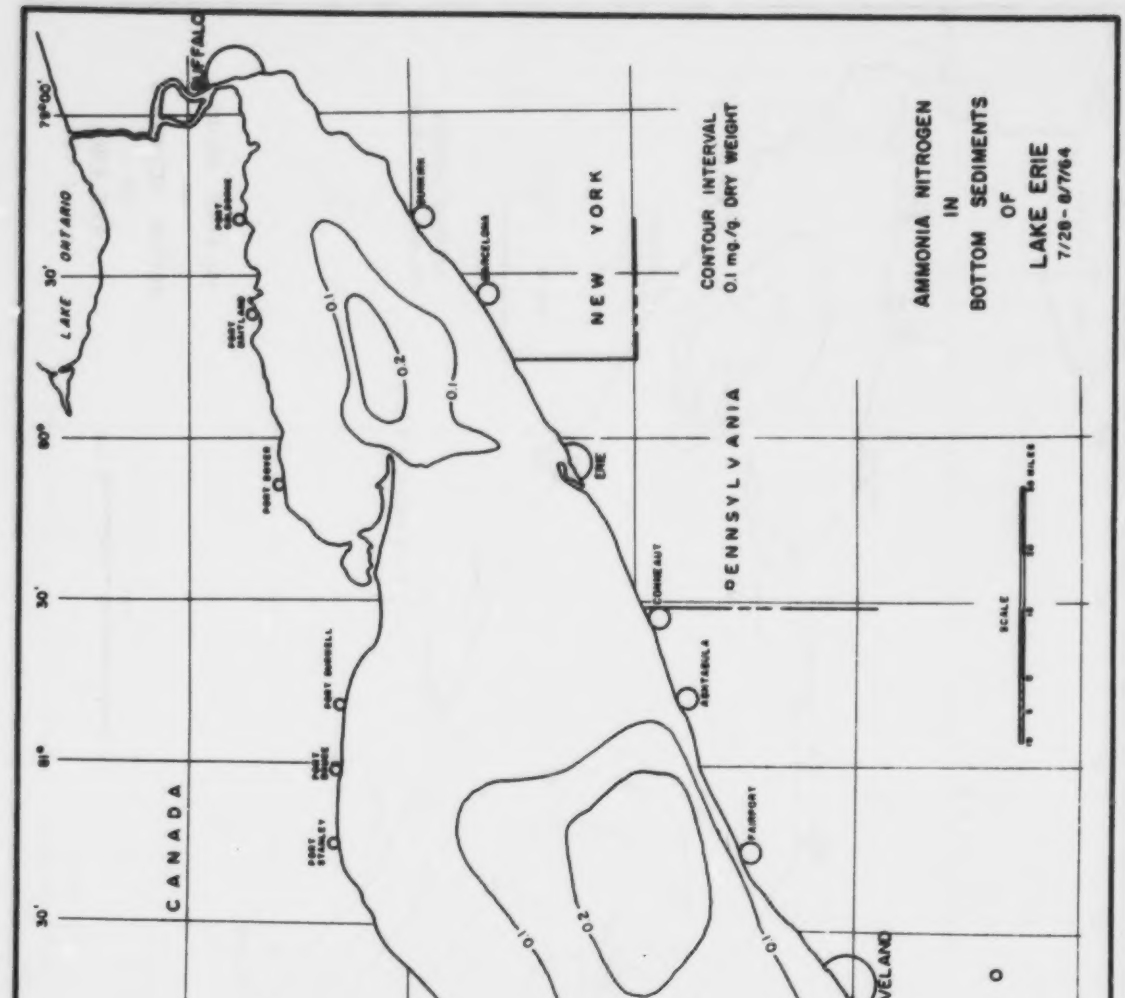
Sample Location	Total Iron	Total Phosphate	Sulfide	Ammonia Nitrogen	NO_2-NO_3 Nitrogen	Organic Nitrogen	Volatile Solids	COD
17	17	1.37	.17	.03	.000	.08	47	33
18	25	2.30	.22	.09	.000	.18	187	73
19	32	3.30	.07	.12	.001	.23	276	84
20	29	1.98	.15	.09	.002	.17	166	49
21	72	2.23	.03	.13	.001	.12	284	50
22	70	2.35	3.62	.16	.005	5.05	387	80
23	43	2.23	.01	.09	.001	.17	251	50
24	45	2.57	3.90	--	.005	9.05	357	86
25	60	1.76	2.21	.10	.008	2.86	267	71
26	22	1.09	.98	.06	.005	1.48	68	57
27	28	1.75	1.30	.09	.003	2.07	748	82
28	47	2.62	2.98	.10	.000	3.10	277	61
29	43	2.78	.13	.21	.000	3.12	326	91
30	26	1.90	.87	.05	.003	2.00	128	47
31	68	2.78	2.99	.18	.005	3.82	390	65
32	30	2.51	.05	.22	.003	2.39	174	79
33	13	1.66	.43	.03	.002	.71	42	19
34	12	1.51	.01	.00	.002	.37	22	37
35	16	0.38	.01	.00	.000	.19	12	3
36	12	0.65	.01	--	.001	.45	25	21
37	21	1.21	.15	.06	.002	1.08	67	31
Avg.	35	1.95	.97	.09	.002	1.84	214	55.7

TABLE 10

BOTTOM SEDIMENT CHEMISTRY - EASTERN BASIN

mg/g

Sample Location	Total Iron	Total Phosphate	Sulfide	Ammonia Nitrogen	NO_2-NO_3 Nitrogen	Organic Nitrogen	Volatile Solids	COD
38	1.2	1.15	.03	.02	.002	0.76	39	26
39	13	1.52	.01	.01	.002	0.02	22	1
40	38	1.56	.05	.07	.002	1.21	63	54
41	1.2	1.32	.01	.01	.005	0.41	43	13
42	.3	1.29	.04	.07	.005	0.95	58	22
43	6	1.22	.07	.19	.000	1.44	87	27
44	26	2.96	.30	.14	.000	2.08	301	59
45	18	2.66	.00	.00	.006	0.57	90	14
46	2.8	0.72	.03	.01	.000	0.33	30	9
47	1.4	0.52	.01	--	.004	--	32	14
48	28	2.61	.03	.28	.010	2.41	176	58
49	45	1.65	.01	.12	.010	--	205	43
50	.02	1.94	.01	.00	.004	--	39	13
51	34	1.95	.28	.00	.009	2.07	126	52
52	24	3.15	.01	.28	.010	1.40	201	79
53	2.1	0.42	.00	.00	.001	0.50	37	19
54	22	1.05	.01	.04	.002	0.50	24	34
55	.23	0.35	.01	.01	.004	0.13	7	8
56	14	1.86	.01	.05	.001	0.00	24	15
57	28	0.57	.09	.05	.002	0.82	40	32
58	5.6	1.21	.00	.01	.001	0.57	23	23
59	14	1.74	.01	.03	.001	0.01	23	20
60	6.8	1.38	.00	.01	.001	--	6	5
Avg.	14.4	1.51	.04	.07	.004	0.85	74	27.8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DUNKIRK
BARCELONA
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ASHTABULA
PORT BURWELL
PORT BRUCE
PORT STANLEY
FAIRPORT
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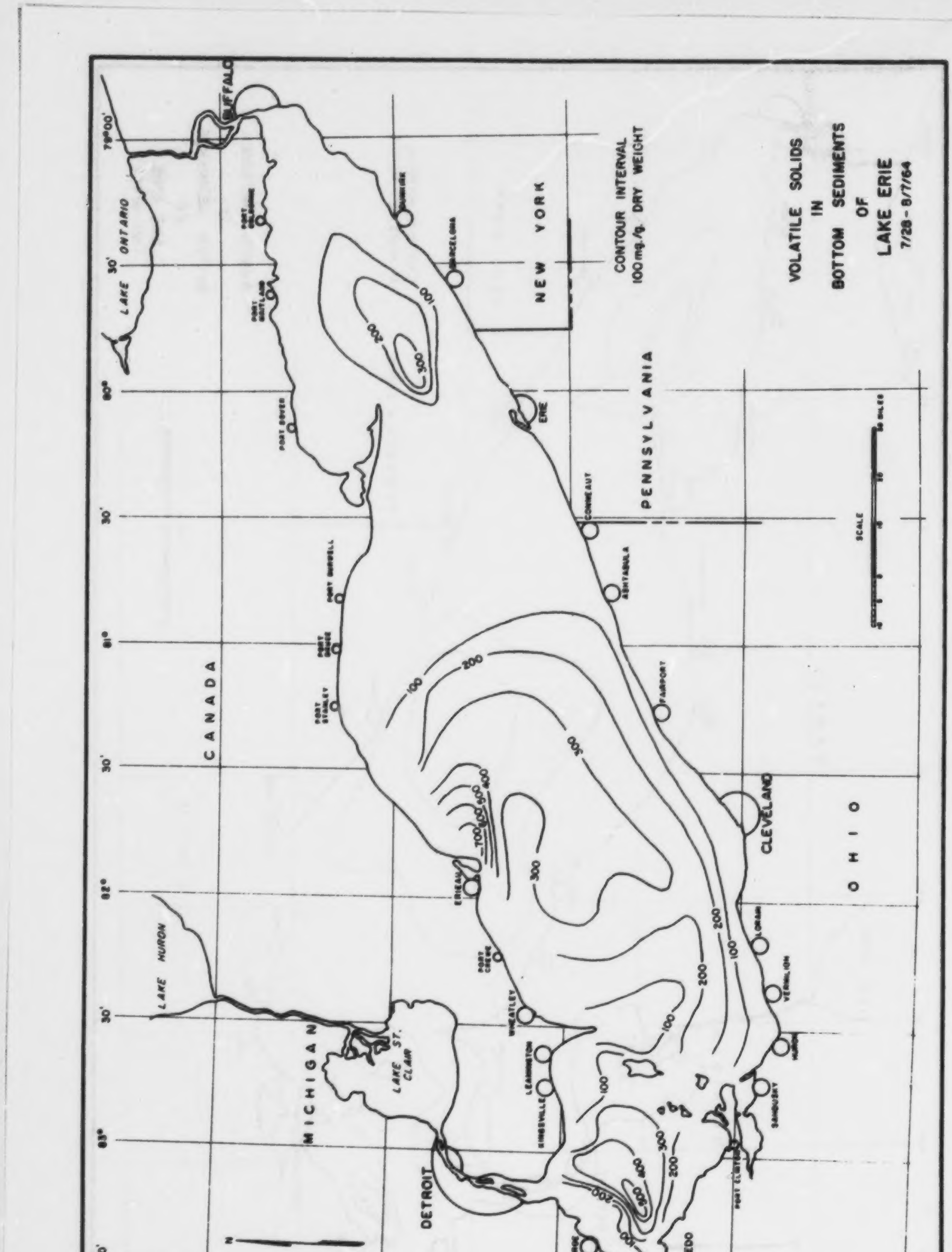
CLEVELAND
OHIO
ERIEAU
PORT CREWE
WHEATLEY
LEAMINGTON
KINGSVILLE
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
TOLEDO
MONROE
DETROIT
MICHIGAN
LAKE ST. CLAIR
LAKE HURON
N
0.1
0.2
0.3
SCALE
MILES

CONTOUR INTERVAL
0.1 mg./g. DRY WEIGHT

AMMONIA NITROGEN
IN
BOTTOM SEDIMENTS
OF
LAKE ERIE
7/28-8/7/64

FIGURE 41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BARCELONA
PORT COLBORNE
PORT MAITLAND
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ASHTABULA
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ERIEAU
LORAIN
PORT CREEK
VERMILION
WHEATLEY
HURON
LEAMINGTON
SANDUSKY
KINGSVILLE
PORT CLINTON
DETROIT
MONROE
TOLEDO
CONTOUR INTERVAL
100 mg./g. DRY WEIGHT
SCALE
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41°

VOLATILE SOLIDS
IN
BOTTOM SEDIMENTS
OF
LAKE ERIE
7/28 - 8/7/64

FIGURE 42

67.4 mg/g in the western basin, 58.3 mg/g in the central basin, and 29.7 mg/g in the eastern basin. This demand is due to organic matter and reduced inorganic species such as ferrous iron and sulfide sulfur. The chemical oxygen demand will vary with the oxidation-reduction potential of the sediment being analyzed. In the central basin, during summer anaerobiasis in the hypolimnion, increases in sediment COD can be expected, due to reduced oxidation-reduction potentials. Chemical oxygen demand values follow volatile solids and total iron directions in each basin.

ALPHA ACTIVITY OF BOTTOM SEDIMENTS

The maximum value was 44 pc/gram. The lowest values tend to be nearer shore, and the areas with higher activity are located in the center of the lake and toward the western end. These high values suggest accumulation following circulatory bottom flow as illustrated in Figure 35.

BETA ACTIVITY OF BOTTOM SEDIMENTS

The mean of all samples was about 38 pc/gram, and the maximum value was 100 pc/gram. Most of this activity is probably due to the long half-life, mixed-fission products of prior fallout from atmospheric detonation of nuclear weapons.

WATER CHEMISTRY

In the course of this investigation, the chemical characteristics of Lake Erie water were measured throughout the lake and at several of its harbors. In most cases the water at each station was sampled several times in both 1963 and 1964; and each time samples were taken at more than one depth, ordinarily at the surface, mid-depth, and just above the bottom. The locations of lake water sampling stations are shown in Figure 43.

For chemical study of the water, the following were measured:

1. Temperature
2. Dissolved oxygen (DO)
3. Chemical oxygen demand (COD)
4. Biochemical oxygen demand (BOD)
5. Conductivity (μmhos at 25°C)
6. Dissolved solids (DS)
7. Total solids (TS)
8. Total alkalinity (as $CaCO_3$)
9. Hydrogen-ion concentration (pH)
10. Chlorides
11. Sulfate (SO_4)
12. Calcium (Ca)

13. Magnesium (Mg)
14. Sodium (Na)
15. Silica (SiO_2)
16. Soluble phosphate (PO_4)
17. Total Nitrogen (N)
18. Ammonia Nitrogen (NH_3-N)
19. Organic Nitrogen (Org-N)
20. Nitrate Nitrogen (NO_3-N)
21. Alkylbenzene sulfonate (ABS)
22. Phenols
23. Toxic metals (zinc, copper, cadmium, nickel, lead, chromium)

Figure 44 depicts graphically the concentrations of major constituents in each of the lake's basins along with input concentrations from the upper lakes.

TEMPERATURE

The water temperature at all sampling stations and at all sample depths was measured with a laboratory thermometer. Also bathythermograph measurements were made at nearly all stations.

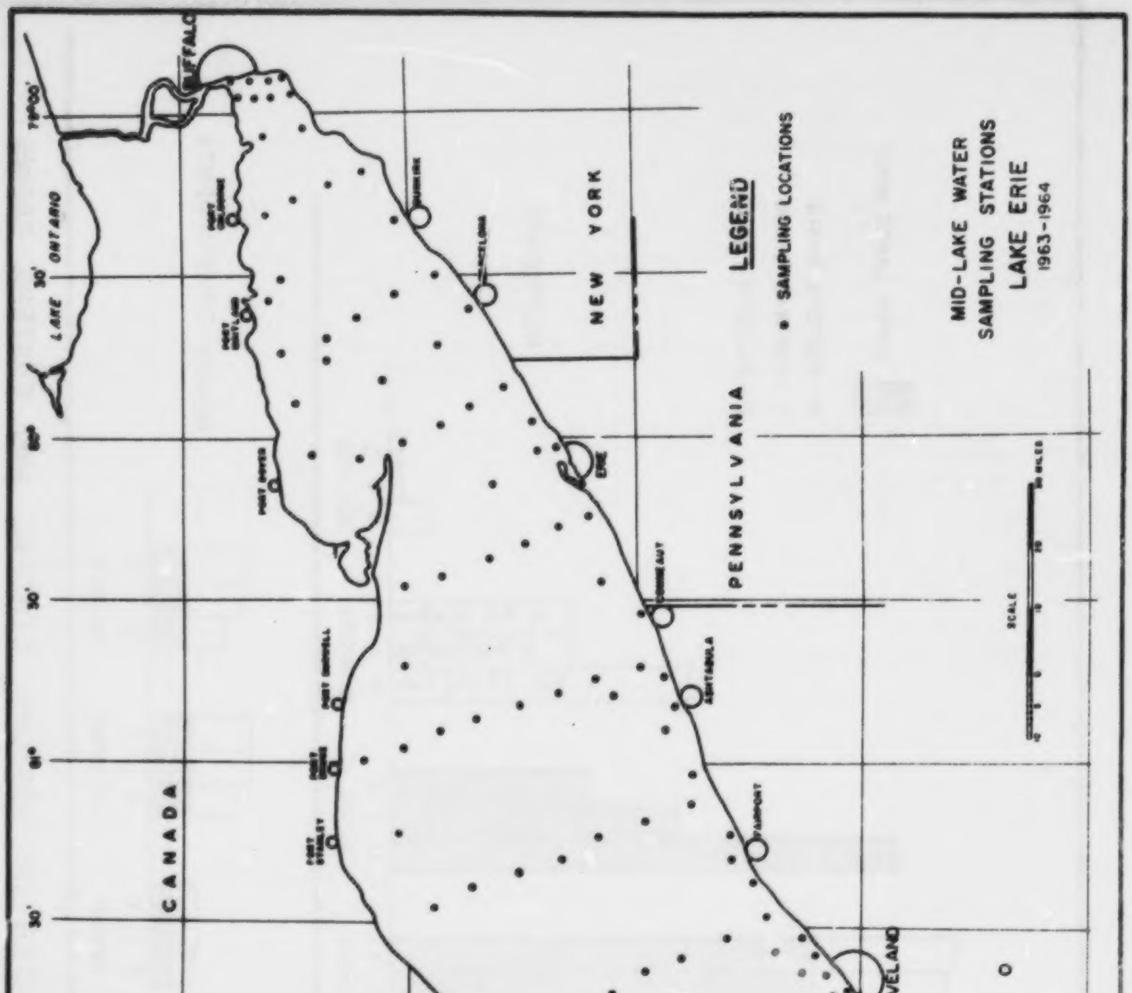
Excessive water temperatures were not encountered at any place in Lake Erie proper during the surveys. Temperatures were, of course, significant in the calculation of percent saturation of oxygen and in the determination of the extent of thermal stratification.

Lake Erie temperatures, as reported, are of no direct significance with regard to water quality. Indirectly, by limiting oxygen dissolution and increasing chemical and biological reaction rates, high temperatures can be important.

DISSOLVED OXYGEN

Dissolved oxygen in Lake Erie, as in all natural waters, is of prime importance in maintaining water quality. It is essential for reduction, purification, and stabilization of wastes. It is also metabolically essential to all types of aquatic life. Adverse effects of high oxygen content are known only in some industrial uses, tending to accelerate corrosion of equipment.

Dissolved oxygen is supplied to pure waters by natural, physical aeration, or absorption from the atmosphere. Oxygen is poorly soluble in water, and since it does not react chemically with water its solubility is directly proportional to its partial pressure. As a result, Boyle's Law may be used to calculate the amounts present at saturation at any given temperature.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LAKE ST. CLAIR
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TOLEDO
CLEVELAND
ERIE
DUNKIRK
CONNEAUT
ASHTABULA
FAIRPORT
LORAIN
VERMILION
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SANDUSKY
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MONROE
KINGSVILLE
LEAMINGTON
WHEATLEY
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PORT DOVER
PORT COLBORNE
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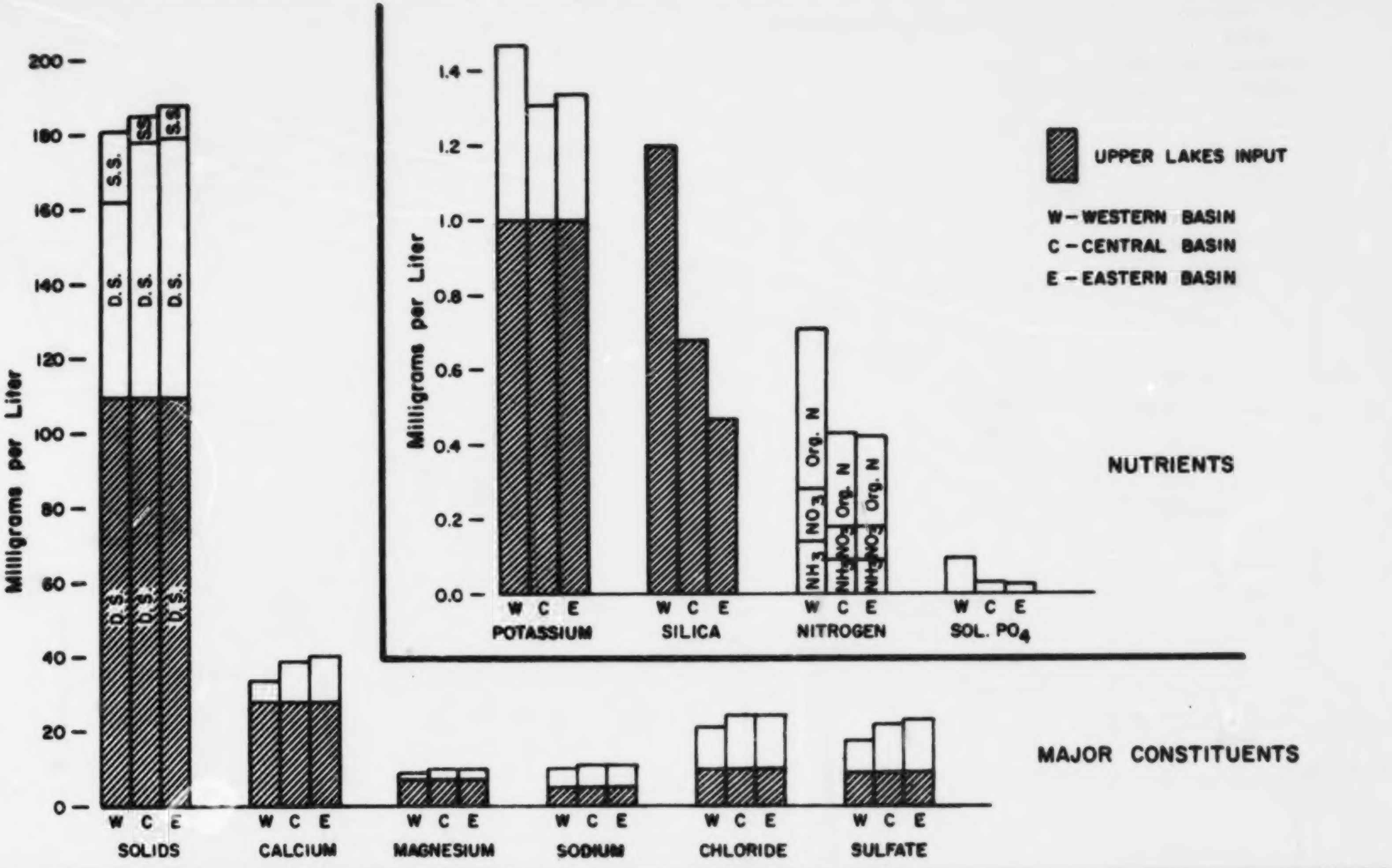
LEGEND
• SAMPLING LOCATIONS

MID-LAKE WATER
SAMPLING STATIONS
LAKE ERIE
1963-1964

FIGURE 43



CHEMISTRY OF LAKE ERIE WATER IN WESTERN, CENTRAL AND EASTERN BASINS

FIGURE 44

Water in the pure state can become temporarily supersaturated with oxygen with a sharp increase in temperature. Ordinarily, however, in Lake Erie, supersaturation results from the photosynthetic process of aquatic plant life. During the daylight hours green algae, utilizing energy from the sun, produce carbohydrates from carbon dioxide and water. In the process copious amounts of oxygen are released to the surrounding water. At night, however, aquatic plant life consumes oxygen through normal respiration. During heavy algal blooms the oxygen may increase to 150 percent of saturation or more, while at night it may decrease to less than 100 percent.

Organic wastes, either natural or synthetic, will decrease the oxygen content of receiving waters. Biochemical oxidation of wastes proceeds at an increased rate with an increase in temperature. The biochemical need for oxygen becomes greater as the oxygen resources become less due to decreased oxygen dissolution with increased temperatures. Most fish also have a need for more oxygen as temperatures rise. A compensating factor is that planktonic oxygen production is increased as temperatures rise, if incident light levels are constant. This can lead to large vertical differences in oxygen content in waters in the same area.

The waters of Lake Erie are normally saturated or nearly saturated with oxygen during the months of October through April and mixing is prevalent from top to bottom. Exceptions may occur only in the immediate vicinity of lakeshore waste outfalls and the mouths of tributaries.

Beginning usually in late May the oxygen content begins to vary in Lake Erie both areally and vertically. Harbors show oxygen deficiencies and a slight reduction occurs in bottom waters of the lake. During the months of May and June oxygen depletions in the central and eastern basins are not serious and 80 percent or more of saturation is common. During these months in the western basin, temporary thermal stratification may occur during prolonged quiescent periods (Carr, Applegate, and Keller, 1964). If the thermocline is near the bottom, oxygen below it may be exhausted for short periods due to the low dissolved oxygen potential of the thin hypolimnion. Reoxygenation occurs when wind turbulence is sufficient to destroy the thermocline.

Stratification in the central basin may occur during the same periods in May and June but the thermocline is shallow and the oxygen content below it is high. Only slight depletion may occur. Saturation values remain essentially constant in the eastern basin during this time.

In June stable stratification is established in the central basin and in the eastern basin. The stratification, except for increasing warmth of the epilimnion waters, stays approximately the same until the lake begins to cool in August. The epilimnion waters normally are from 90 to 100 percent of saturation. Hypolimnion water, that part below the thermocline, decreases in oxygen content throughout the summer. It may reach zero in the central basin where the hypolimnion is thin. It may decline to 60 or 70 percent of saturation in the eastern basin below the thermocline. Low dissolved oxygen was first observed in the central basin in 1929 (Fish, 1955). Since then it has occurred more frequently and for longer periods.

In the western basin in mid-summer, dissolved oxygen in the surface waters is maintained at or above 100 percent saturation while bottom waters are somewhat lower, generally between 50 and 75 percent. However, intermittent stratification occurs throughout the summer with proper weather conditions. As previously described, oxygen may be completely exhausted locally in bottom waters at these times. In addition, the bottom waters have high temperatures, oxidation of organic sediments can be rapid, and oxygen depletion is quickly accomplished. Carr, Applegate, and Keller (1964) report that it now takes only five days of meteorological and consequent hydrological quiescence to result in oxygen exhaustion, whereas in 1953 it required 28 days.

The lake begins to cool in August. Stratification occurs less frequently or not at all in the western basin from that time on. However, in the central basin depletion becomes more severe since the thermocline moves downward, the hypolimnion becomes thinner, and the oxygen contained therein is biologically assimilated.

Oxygen depletion of significance occurs in nearshore waters only in harbor areas and tributary mouths which are receptacles for large volumes of wastes. The most severe conditions occur in Cleveland Harbor and locally in Erie and Buffalo Harbors. Others with less severe but still serious problems are the mouths of the Detroit, Raisin, and Maumee Rivers. Conditions in these areas are more severe upstream away from lake dilution.

CHEMICAL OXYGEN DEMAND

The chemical oxygen demand (COD) has been determined on several hundred water samples taken throughout Lake Erie. Determinations were made employing the potassium dichromate method. Although it gives the order of magnitude of the ultimate biochemical oxygen demand (BOD), it is not a substitute for that determination. Indications of the rate of natural oxidation are not provided and differentiation between biologically oxidizable, and biologically inert organic matter is not discernible.

The COD of Lake Erie water samples is important in that it provides an indication of degree of pollution and provides a basis for areal comparison. COD results of the lake samples do not indicate adverse water quality conditions. Extreme and average COD for samples from each of the basins are shown in Table II.

The COD of western basin water during the summers of 1963 and 1964, averaged 10.4 mg/l with extremes of 6.5 and 28.0 mg/l. Highest values were in the western one-third of the basin with a general decrease eastward. In the central basin the average was 7.1 mg/l with extremes of 3.1 and 16.0 mg/l. The eastern basin ranged between 6.1 and 27.0 with an average of 7.4 or approximately the same as the central basin. The highest values were near the south shore.

In harbor waters the highest COD of 53 mg/l was found near the mouth of the Maumee River. High values were also found in Sandusky Bay and Erie Harbor.

BIOCHEMICAL OXYGEN DEMAND

Determinations of 5-day biochemical oxygen demand (BOD_5) were not made on mid-lake samples except for a few on one cruise (66) in August 1964. However, numerous determinations were made in the nearshore zone along the south shore. Samples were taken only during the summer months in 1964, between May and September. BOD analyses were made on Detroit River samples by the FWPCA Detroit River Project.

Highest BOD_5 values were found in Sandusky Bay, averaging 3.8 mg/l; Erie Harbor, averaging 3.3 mg/l; and in Ashtabula Harbor, averaging 3.2 mg/l. Lorain and Cleveland harbors averaged about one-half these values. BOD_5 values at the mouth of the Detroit River ranged from 2 to 5 mg/l.

BOD_5 values decrease rapidly with distance from shore. The Bureau of Commercial Fisheries reports that central basin hypolimnion water averages about 1 mg/l BOD_5. A maximum of 1.5 mg/l was found by the FWPCA in the hypolimnion in August 1964.

The BOD_5 values indicate that outside the nearshore areas (widest along the Michigan shore and the Maumee Bay area) the water of Lake Erie is of high quality in this respect.

CONDUCTIVITY AND DISSOLVED SOLIDS

A good general indicator of the chemical water quality of Lake Erie is the dissolved solids content which is the content of dissolved elements and compounds. Conductivity, or the capacity of the water to conduct an electrical current, is directly related to the dissolved solids content or the ionic concentration. In offshore waters, several hundred measurements have shown that conductivity in micromhos/cm at 25°C divided by 1.66 equals the dissolved solids content in milligrams/liter. This relation does not necessarily hold in nearshore and harbor

TABLE 11

C.O.D. CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	--	--	--	--	--	--
40	5/63	--	--	--	--	--	--	--	--	--
42	6/63	--	--	--	--	--	--	--	--	--
52	10/63	10.6	3.5	6.5	8.6	3.1	6.4	20.9	4.7	6.9
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	13.1	7.5	10.7	--	--	--	--	--	--
58	5/64	--	--	--	16.0	3.6	8.4	27.0	5.7	8.8
61	6/64	28.0	4.2	12.3	--	--	--	--	--	--
62	6/64	--	--	--	6.0	5.0	5.5	7.0	6.0	6.1
66	8/64	--	--	--	9.0	7.0	8.1	13.0	6.0	8.0
67	9/64	29.0	1.1	12.0	--	--	--	--	--	--
Avg.				10.37			7.10			7.45

Michigan waters of Lake Erie not included.

areas where the content of one or more salts may be excessive.

Table 12 and 13 list the conductivity values and dissolved solids concentrations for the three basins as maxiumums, minimums, and averages for each of the mid-lake cruises in 1963 and 1964. Important is the fact that the average concentration of dissolved solids in the central and eastern basins is virtually identical at 180 mg/l, while the average concentration in the western basin is about 18 mg/l lower. However, the range of values is greatest in the western basin and decreases eastward, indicating an increasing tendency toward uniformity to the east. Conductivity values show the same pattern.

The lowest dissolved solids concentration found during the sampling of Lake Erie was 110 mg/l at the mouth of the Detroit River in the mid-channel flow. This value is near that for the average concentration in Lake Huron as reported by Beeton (1965). in the eastern basin the value is 179 mg/l; therefore, a net increase of 69 mg/l occurs in Lake Erie. However, 75 percent of that increase occurs in the western basin indicating the comparative severity of chemical loading from sources near the west end of the lake (Figure 44).

Dissolved solids content has been increasing in Lake Erie at a fairly rapid rate since the turn of the century (Figure 45). Dissolved solids content along the shore is generally higher and at some places is now excessive. Of particular concern are the concentrations in Sandusky Bay with values up to 700 mg/l, and the bottom waters in Fairport Harbor with values of more than 3,000 mg/l. Sulfates and chlorides account for most of these higher values.

Dissolved solids cannot be expected to decrease in the future. In fact the rate of increase may be expected to rise with increased population and activity around the lake unless discharges are rigidly controlled.

TOTAL SOLIDS

Total solids are the evaporation residue from unfiltered samples. Suspended solids, those not in solution, are equal to the total solids less the dissolved solids.

In central and eastern basin mid-lake, the total solids are nearly equal in concentration with average values of 185 and 188 mg/l, respectively (see Table 14 and Figure 44). Western basin water is also approximately equal at 181 mg/l.

Suspended solids average less than 10 mg/l in the central and eastern basins. Western basin values are double this amount, and during the survey period reached a maximum of about 50 mg/l. This may further

TABLE 12

CONDUCTIVITY IN LAKE ERIE
umhos/cm
at 25°C

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	—	—	—	—	—	—	—	—	—
40	5/63	300	262	286	328	260	291	296	275	289
42	6/63	—	—	—	353	312	324	328	314	319
52	10/63	304	216	259	330	254	290	320	284	292
55	4/64	—	—	—	—	—	—	—	—	—
57	5/64	334	220	268	—	—	—	—	—	—
58	5/64	—	—	—	330	276	289	—	—	—
61	6/64	364	222	286	—	—	—	—	—	—
62	6/64	—	—	—	—	—	—	—	—	—
66	8/64	—	—	—	344	284	305	324	296	305
67	9/64	310	196	263	—	—	—	—	—	—
Avg.				272			300			301

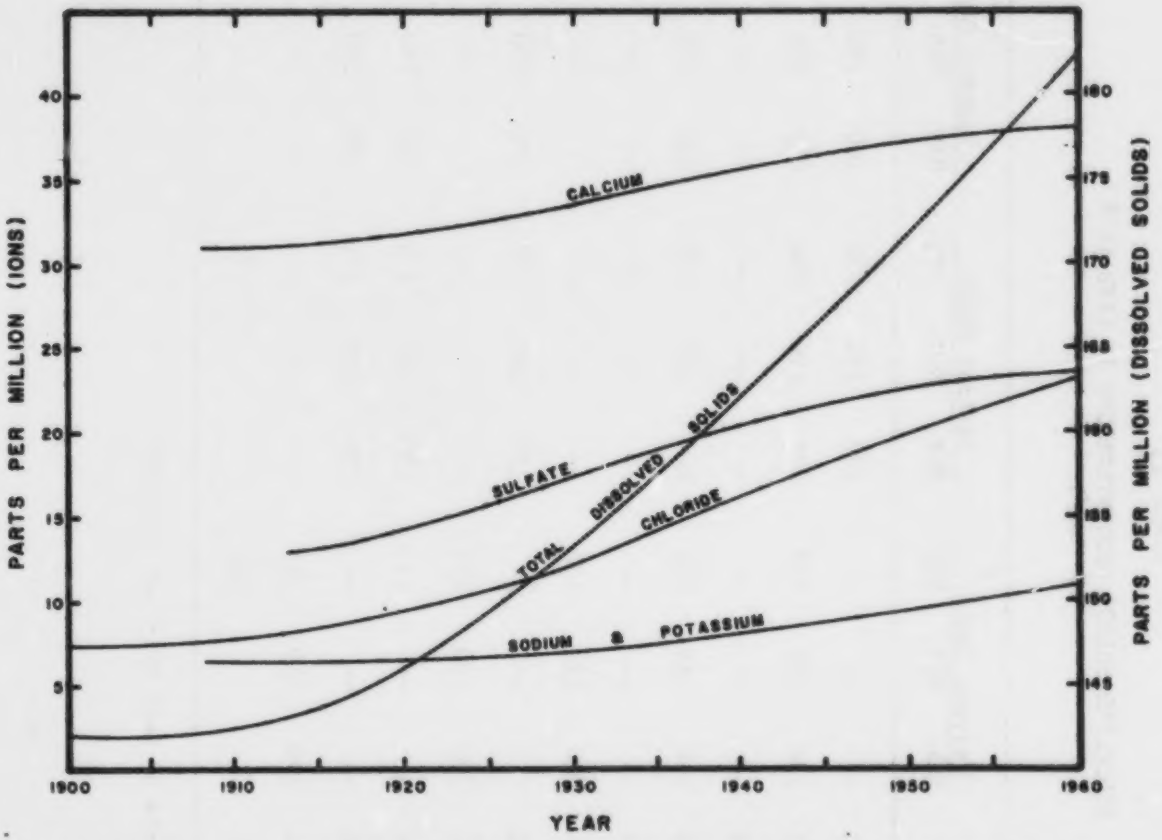
Michigan waters of Lake Erie not included.

TABLE 13

DISSOLVED SOLIDS CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	180	155	170	190	160	182
40	5/63	186	172	177	239	190	204	233	183	205
42	6/63	--	--	--	--	--	--	--	--	--
52	10/63	198	135	156	209	137	175	205	161	184
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	200	120	152	--	--	--	--	--	--
58	5/64	--	--	--	180	160	177	190	160	175
61	6/64	220	120	170	--	--	--	--	--	--
62	6/64	--	--	--	190	140	170	160	150	158
66	8/64	--	--	--	180	170	171	190	160	172
67	9/64	190	110	153	--	--	--	--	--	--
Avg.				162			178			179

Michigan waters of Lake Erie not included.



CHANGES IN CHEMICAL CHARACTERISTICS OF LAKE ERIE

(ADAPTED FROM BEETON, 1965)

FIGURE 45

TABLE 14

TOTAL SOLIDS CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	--	--	--	--	--	--
40	5/63	--	--	--	--	--	--	--	--	--
42	6/63	--	--	--	--	--	--	--	--	--
52	10/63	196	147	166	218	159	186	222	167	193
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	250	150	187	--	--	--	--	--	--
58	5/64	--	--	--	200	190	192	200	190	192
61	6/64	250	150	188	--	--	--	--	--	--
62	6/64	--	--	--	200	175	191	200	180	191
66	8/64	--	--	--	180	170	171	240	170	178
67	9/64	230	140	181	--	--	--	--	--	--
Avg.				181			185			188

Michigan waters of Lake Erie not included.

increase during storms and periods of heavy runoff.

The minimum total solids concentration was found at the mouth of the Detroit River in the mid-channel flow with a value of 140 mg/l. This is 48 mg/l less than the average for the eastern basin, providing a comparison of Detroit River inflow and Niagara River outflow.

CHLORIDES

Chlorides are among the most stable of the dissolved substances, unaffected by chemical, biochemical, or physical reaction. Although they are generally found in acceptably low concentrations, they are very important in tracing sources of significant municipal and industrial pollution. Chloride monitoring is useful in establishing long-term trends in general water quality. Chlorides have increased threefold (Beeton, 1964) in Lake Erie since 1900 (Figure 45).

Maximum, minimum, and average values for mid-lake waters on each cruise are shown in Table 15. During the survey period the chlorides in the western basin away from nearshore areas averaged 21.3 mg/l. In the central basin the average was 24.5 mg/l and in the eastern basin 24.4 mg/l. The lowest value recorded was 10 mg/l at the mouth of the Detroit River in the mid-channel flow. If this is used as a base, or inflow concentration, then 11.3 mg/l are gained in the western basin and 3.2 in the central and eastern basins. Thus 77 percent of the gain is derived from inputs to the western basin (see Figure 44).

In nearshore waters chloride values are higher (Table 29). Along the west side of the Detroit River and along the Michigan shore, values of more than 40 mg/l are common. It is from this area of the basin that most chlorides originate. Maumee Bay, Sandusky Bay, and Lorain Harbor do not show concentrations much above the average lake values. Cleveland Harbor averages 35 mg/l and ranges up to about 90 mg/l. Ashtabula and Erie Harbors both average more than 30 mg/l. By far the highest values have been found in Fairport Harbor, with concentrations up to 350 mg/l in the upper water and up to ten times this amount in the bottom waters. Chloride concentrations are so high that they create a permanent density stratification in and around Fairport Harbor. High concentrations and subsequent stratification dissipate to background lake values within a few miles.

SULFATES

Sulfates, like chlorides, are among the more persistent of dissolved compounds and are generally found in acceptably low concentrations. They can be useful as tracers for pollution sources if natural background levels are known. They are also important in establishing long-term trends in water quality. They have increased in concentration by 90 percent in Lake Erie since 1910 (Figure 45) but now appear to be leveling off.

TABLE 15

CHLORIDE CONCENTRATIONS IN LAKE ERIE
mg/1

Cruise	Date	Western Basin			Central Basin			Eastern Basin		
		Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	31	21	24	25	22	23
40	5/63	22	16	19	33	20	24	28	21	24
42	6/63	--	--	--	--	--	--	--	--	--
52	10/63	29	10	18	31	19	22	25	21	22
55	4/64	34	15	21	46	23	24	31	22	24
57	5/64	32	12	22	--	--	--	--	--	--
58	5/64	--	--	--	28	26	27	27	27	27
61	6/64	31	13	25	--	--	--	--	--	--
62	6/64	--	--	--	26	25	26	28	24	26
66	8/64	--	--	--	--	--	--	29	23	25
67	9/64	32	11	23	--	--	--	--	--	--
Avg.				21.3			24.5			24.5

Michigan waters of Lake Erie not included.

Table 16 lists maximum, minimum, and average concentrations in each basin for each sampling cruise. In the western basin for the periods of the surveys in 1963 and 1964, sulfates ranged from 9 to 35 mg/l in open waters with an average of 17.7 mg/l. In the central basin the range was 15 to 43 mg/l with an average of 22.4 mg/l. The range in the eastern basin water was 17 to 33 mg/l with an average of 23.4 mg/l. Using the value of 9 mg/l as the concentration derived from upper lakes inflow, there is a gain in Lake Erie of 14.4 mg/l. Inputs to the western basin account for 60 percent of that gain, with 40 percent from central and eastern basin sources (Figure 44).

In the nearshore zone significant concentrations have been found in Sandusky Bay with an average of 127.1 mg/l. Lorain and Erie Harbors did not show high concentrations. Sulfate levels at other harbors were low, but upstream data indicate that the Cuyahoga and Grand Rivers supply significant amounts. Obviously large quantities must be derived from the Detroit-Monroe-Toledo area. Concentrations at the Monroe, Michigan water intake are normally more than twice the average in the western basin.

CALCIUM

Hardness is caused by divalent metallic ions that are capable of reacting with soap to form precipitates and with certain anions in the water to form scale. Calcium is the principal cation associated with this effect, and as such, knowledge of its concentration is necessary for the production of satisfactory water for domestic and industrial uses.

Calcium, in its concentration pattern, is similar to sulfates in Lake Erie (Table 17 and Figure 44). Its average concentration in the western basin water is 33.9 mg/l with a maximum of 43 mg/l and a minimum of 28 mg/l. In the central basin it ranges between 32 and 49 mg/l with an average of 39.5 mg/l, while in the eastern basin it averages 40.5 mg/l and ranges between 36 and 49 mg/l.

If the value of 28 mg/l is near that originating in the upper lakes, then calcium is not appreciably accumulating in Lake Erie. Compared to most other constituents, the accumulation from western basin sources is rather low, being only 47 percent of the total accumulating in Lake Erie exclusive of upper lakes input. An additional 45 percent accumulates from additions to the central basin, while the remaining 8 percent accumulates from eastern basin additions. Large quantities of calcium have been found in Sandusky Bay, averaging 65 mg/l and ranging up to 114 mg/l.

Calcium concentrations have increased only a small amount in Lake Erie during the past 30 years (Figure 45). Calcium will react with

TABLE 16

SULFATE CONCENTRATIONS IN LAKE ERIE
mg/l

Cruise	Date	Western Basin			Central Basin			Eastern Basin		
		Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	28	22	24.2	29	20	24.1
40	5/63	21	11	17.7	43	21	24.8	25	22	23.7
42	6/63	25	18	21.2	31	18	23.5	26	23	24.3
52	10/63	23	14	17.7	25	15	21.0	33	18	26.4
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	35	11	17.1	--	--	--	--	--	--
58	5/64	--	--	--	25	20	21.3	23	17	20.1
61	6/64	30	9	16.6	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	22	18	19.8	26	18	21.8
67	9/64	28	9	16.2	--	--	--	--	--	--
Avg.				17.7			22.4			23.4

Michigan waters of Lake Erie not included.

TABLE 17

CALCIUM CONCENTRATIONS IN LAKE ERIE
mg/1

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	38	37	37.3	40	36	38.5
40	5/63	37	28	32.4	44	34	37.4	39	36	37.9
42	6/63	37	32	34.5	39	34	36.8	40	36	38.0
52	10/63	34	29	32.2	49	32	40.2	44	40	41.4
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	43	31	36.1	--	--	--	--	--	--
58	5/64	--	--	--	47	46	46.5	49	47	47.6
61	6/64	42	29	35.4	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	41	38	38.9	42	38	39.9
67	9/64	37	28	33.3	--	--	--	--	--	--
Avg.				33.9			39.5			40.5

Michigan waters of Lake Erie not included.

phosphates, sulfates, and carbonates at prevailing Lake Erie hydrogen ion concentrations (above pH 8.0) to form insoluble precipitates, thus creating a stabilizing calcium effect.

Calcium in Lake Erie presents no known health hazard. In addition it may be important in moderating phosphate concentrations by precipitating them from solution.

MAGNESIUM

Magnesium also is considered as hardness but in Lake Erie is one of the more insignificant constituents. Its content averages 8.7 mg/l in the western basin, 10.0 mg/l in the central basin, and 10.0 mg/l in the eastern basin (Table 18 and Figure 44).

If the minimum of 7 mg/l found at the mouth of the Detroit River in the mid-channel flow is taken as the concentration of the upper lakes input, then only 3 mg/l are added to Lake Erie from basin sources. Fifty-seven percent of this amount is added from western basin sources. Comparatively large concentrations, averaging 22 mg/l, have been found in Sandusky Bay.

Magnesium concentrations are not expected to increase significantly in Lake Erie.

SODIUM

Sodium has little sanitary significance in Lake Erie. It is an indicator of relative quantities of salt being discharged to the lake and thus an indicator to trends in chemical water quality. However, sodium does have public health significance. In cases of cardiovascular deficiency, it is imperative that sodium intake be kept at a minimum. Waste sources to Lake Erie are from brine discharges. Maximum, minimum, and average concentrations for each basin are shown in Table 19.

Sodium concentrations in the western basin water averages 9.9 mg/l and ranges between 4.7 and 19 mg/l. In the central basin the average concentration increases to 11.0 mg/l, ranging between 8.3 and 17 mg/l. The eastern basin is essentially the same as the central basin with an average of 10.9 mg/l and a range of 9.3 to 15 mg/l.

The low of 4.7 mg/l is near the average for the discharge concentration from the upper lakes. This concentration more than doubles within Lake Erie, and 83 percent of this increase results from discharges to the western basin (Figure 44).

POTASSIUM

Potassium, like sodium, has no great sanitary significance in the

TABLE 18

MAGNESIUM CONCENTRATIONS IN LAKE ERIE
mg/l

Cruise	Date	Western Basin Max.	Western Basin Min.	Western Basin Avg.	Central Basin Max.	Central Basin Min.	Central Basin Avg.	Eastern Basin Max.	Eastern Basin Min.	Eastern Basin Avg.
9	4/63	--	--	--	11	10	10.2	11	10	10.1
40	5/63	10	9	9.3	10	10	10.0	11	10	10.1
42	6/63	9	8	8.7	9	7	8.2	9	7	8.4
52	10/63	9	8	8.1	10	8	8.9	10	8	9.0
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	11	7	8.5	--	--	--	--	--	--
58	5/64	--	--	--	14	13	13.3	14	12	12.8
61	6/64	11	8	9.3	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	11	9	9.7	11	8	9.6
67	9/64	11	7	8.4	--	--	--	--	--	--
Avg.				8.7			10.0			10.0

Michigan waters of Lake Erie not included.

TABLE 19

SODIUM CONCENTRATIONS IN LAKE ERIE
mg/l

Cruise	Date	Western Basin			Central Basin			Eastern Basin		
		Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	12.0	8.9	9.75	9.9	9.4	9.51
40	5/63	9.0	6.8	7.78	12.3	8.3	9.65	10.5	8.6	9.30
42	6/63	11.2	8.5	9.80	14.7	9.0	10.20	12.7	9.5	10.62
52	10/63	13.0	4.7	8.47	13.0	9.5	10.80	15.0	10.0	11.18
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	17.0	6.4	10.91	--	--	--	--	--	--
58	5/64	--	--	--	17.0	13.0	14.50	14.0	12.0	12.83
61	6/64	17.0	5.5	11.24	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	13.0	11.0	11.43	13.0	11.0	11.72
67	9/64	19.0	5.7	11.27	--	--	--	--	--	--
Avg.				9.91			11.05			10.86

Michigan waters of Lake Erie not included.

Great Lakes. In most natural waters it is reported as a part of "sodium-plus-potassium" because of low concentrations and analytical complexities. Peculiarly, as concentrations of both these elements increase in natural waters, the proportion of sodium to potassium increases. In Lake Erie the ratio of sodium to potassium is about 8 to 1. Sodium plus potassium has approximately doubled in concentration in Lake Erie since 1920 (Figure 45).

Potassium is an essential nutrient for aquatic life and can be limiting in natural waters.

The potassium concentrations found in each of the basins are shown in Table 20 and Figure 44. The concentration of potassium in the western basin water averages 1.47 mg/l and varies from 1.0 to 4.5 mg/l. In the central basin it averages 1.31 mg/l and ranges from 1.1 to 1.6 mg/l, while in the eastern basin the average is about the same at 1.34 mg/l and the range is 1.1 to 1.9 mg/l.

Placing the Detroit River mid-channel input concentration at 1.0 mg/l, there is a 47 percent gain in the western basin and then an 11 percent drop between the western and central basins. The drop may represent uptake by aquatic life or dilution by lower-level potassium waters.

Sandusky Bay averaged 2.6 mg/l and ranged up to 4 mg/l, indicating it as an important source of potassium. The Michigan shore waters, with concentrations above 4 mg/l, indicated large sources in that area. Cleveland Harbor concentrations were similar. Other sources along the United States shore do not appear to be significant.

SILICA

Dissolved silica (SiO_2) in Lake Erie is one of the few constituents which shows lower concentrations, on the average, than the upper lakes. Presumably, this is due to uptake and precipitation by aquatic organisms, principally diatoms. Silica in natural waters has no known health significance. It has some significance in industrial use, especially in high pressure boiler feed water.

In the western basin the water averages 1.20 mg/l silica and ranges from 0.3 to 5.0 mg/l (Table 21 and Figure 44). In the central basin the average decreases to 0.68 mg/l, ranging from 0.2 to 3.5 mg/l. The eastern basin water averages 0.47 mg/l and ranges from 0.2 to 3.5 mg/l.

All tributaries contribute silica, since silica is a universal mineral. The most important sources are soil and land runoff, and mineral refining industries.

Silica will not significantly increase the dissolved solids content of Lake Erie.

TABLE 20

POTASSIUM CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	—	—	—	1.4	1.1	1.18	1.4	1.1	1.21
40	5/63	4.5	1.1	2.30	1.3	1.1	1.23	1.5	1.1	1.28
42	6/63	1.3	1.1	1.17	1.6	1.1	1.23	1.4	1.1	1.23
52	10/63	1.5	1.0	1.20	1.6	1.1	1.38	1.6	1.3	1.44
55	4/64	—	—	—	—	—	—	—	—	—
57	5/64	3.6	1.0	1.35	—	—	—	—	—	—
58	5/64	—	—	—	1.5	1.3	1.43	1.9	1.4	1.60
61	6/64	2.3	1.0	1.32	—	—	—	—	—	—
62	6/64	—	—	—	—	—	—	—	—	—
66	8/64	—	—	—	1.6	1.3	1.41	1.9	1.1	1.32
67	9/64	2.0	1.1	1.50	—	—	—	—	—	—
Avg.				1.47			1.31			1.34

Michigan waters of Lake Erie not included.

TABLE 21

SILICA CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	1.4	0.2	0.52	1.2	0.4	0.61
40	5/63	1.8	0.8	1.36	1.1	0.3	0.60	0.8	0.2	0.35
42	6/63	5.0	0.7	1.87	3.5	0.3	0.75	3.4	0.3	0.71
52	10/63	1.6	0.4	0.83	1.2	0.2	0.41	0.6	0.2	0.29
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	2.0	0.4	1.13	--	--	--	--	--	--
58	5/64	--	--	--	0.6	0.3	0.42	0.4	0.2	0.30
61	6/64	2.6	0.3	1.04	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	9.6	0.3	1.37	3.5	0.2	0.57
67	9/64	1.8	0.3	1.00	--	--	--	--	--	--
Avg.				1.20			0.68			0.47

Michigan waters of Lake Erie not included.

ALKYL BENZENE SULFONATE (ABS)

This compound (ABS), up until July 1965, was a constituent of synthetic detergents. It is difficultly degradable and is a rather stable part of receiving waters. In excessive quantities, more than 1 mg/l, it imparts a disagreeable taste and will foam. Much higher concentrations have not produced any toxic effects on humans, however, this has not been ascertained on aquatic life. The USPHS drinking water standards recommend a limit of 0.5 mg/l based on taste and foam production. This value in Lake Erie has not been exceeded.

The average concentration of ABS in the western basin water in 1963 and 1964 was 0.067 mg/l, in the central basin 0.065 mg/l, and 0.065 mg/l in the eastern basin (Table 22). Sample values ranged from 0.01 mg/l to 0.20 mg/l. Most nearshore areas range within the same values.

SOLUBLE PHOSPHORUS

Soluble phosphorus is a minor constituent, quantity-wise, in Lake Erie. It has no public health significance, nor is it an important factor in regard to chemical water quality in concentrations now found in the lake. However, its concentration is a very important controlling factor in Lake Erie's major water quality problem, the problem of eutrophication or the over-production of attached and planktonic plants. Phosphorus is a limiting nutrient.

The maximum, minimum, and average concentrations in each basin for all cruises are shown in Table 23. In the western basin of Lake Erie, soluble phosphorus, during the 1963-64 surveys, averaged 0.032 mg/l and ranged from 0.003 to 0.333 mg/l. The average was 0.010 mg/l in both the central and eastern basins. The range in the central basin was from 0.000 to 0.066 mg/l and in the eastern basin from 0.000 to 0.033 mg/l. Figure 44 shows phosphate (PO_4) values. Phosphorus is equal to one-third these values.

The input of soluble phosphorus from the upper lakes appears to be approximately 0.005 mg/l. If this is true, there is nearly a six-fold increase in the western basin of Lake Erie. However, this is followed by a 60 percent decrease in the phosphate level of the central and eastern basins. The decrease apparently results from both chemical and biochemical precipitation and biological storage within the lake. Figure 46 shows the soluble phosphorus distribution in the western basin for one cruise in September 1964 in which the west to east decrease is apparent.

Nearshore values generally are higher in the vicinity of tributaries and harbors. Maumee Bay averaged 0.027 mg/l of soluble phosphorus during the time of survey but apparently at times of heavy runoff the amount is higher. Concentrations of 0.066 or more are prevalent along the Michigan shore. Relatively high levels of phosphorus have been found in Sandusky

TABLE 22

ABS CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	0.07	0.03	0.038	0.07	0.03	0.040
40	5/63	0.06	0.05	0.053	0.18	0.03	0.072	0.15	0.04	0.087
42	6/63	0.14	0.05	0.090	0.17	0.02	0.058	0.17	0.04	0.077
52	10/63	0.14	0.07	0.097	0.20	0.04	0.083	0.15	0.03	0.076
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	0.10	0.5	0.075	--	--	--	--	--	--
58	5/64	--	--	--	0.07	0.06	0.065	0.07	0.06	0.065
61	6/64	0.06	0.01	0.033	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	0.12	0.05	0.075	0.10	0.03	0.045
67	9/64	0.12	0.01	0.055	--	--	--	--	--	--
Avg.				0.067			0.065			0.065

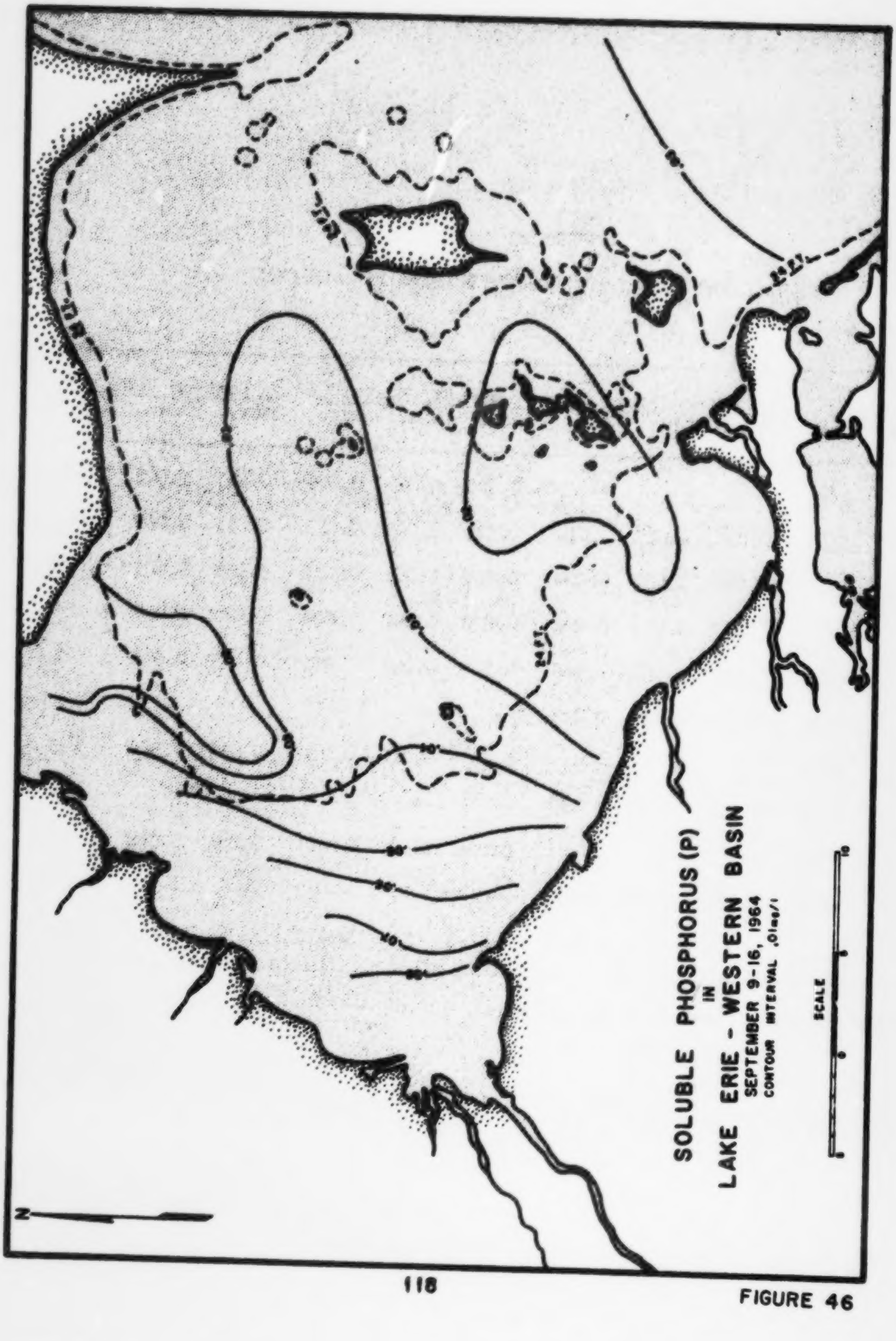
Michigan waters of Lake Erie not included.

TABLE 23

SOLUBLE PHOSPHORUS (P) CONCENTRATIONS IN LAKE ERIE
mg/1

Cruise	Date	Western Basin			Central Basin			Eastern Basin		
		Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	0.020	0.003	0.009	0.017	0.003	0.009
40	5/63	0.024	0.007	0.014	0.020	0.003	0.011	0.017	0.007	0.011
42	6/63	0.010	0.007	0.009	0.040	0.003	0.005	0.033	0.003	0.009
52	10/63	0.017	0.003	0.008	0.023	0.000	0.008	0.027	0.000	0.006
55	4/64	0.333	0.007	0.068	0.027	0.007	0.014	0.017	0.010	0.014
57	5/64	0.030	0.007	0.013	--	--	--	--	--	--
58	5/64	--	--	--	0.037	0.000	0.012	0.037	0.000	0.013
61	6/64	0.240	0.024	0.080	--	--	--	--	--	--
66	8/64	--	--	--	0.066	0.000	0.013	0.024	0.000	0.006
67	9/64	0.123	0.003	0.034	--	--	--	--	--	--
Avg.				0.032			0.010			0.010

Michigan waters of Lake Erie not included.


N
SCALE
0
5
10

SOLUBLE PHOSPHORUS (P)
IN
LAKE ERIE - WESTERN BASIN
SEPTEMBER 9-16, 1964
CONTOUR INTERVAL .01mg/l

FIGURE 46

Bay (up to 0.056 mg/l) and Lorain Harbor (up to 0.037 mg/l). The Cuyahoga River, in places, shows extremely high concentrations of soluble phosphorus. The outer harbor has not shown these high values, apparently because of chemical precipitation in the channel. The other harbors along Lake Erie have not shown abnormally high concentrations.

TOTAL PHOSPHORUS

Total phosphorus analyses were not made on mid-lake waters for this study. Total phosphorus includes both soluble and insoluble organic and inorganic phosphorus. It is apparent that phosphorus can change in biochemical processes from the soluble to insoluble form and vice versa. As a result, the measure of total phosphorus is more valid in the evaluation of nutrient potential than is soluble phosphorus determination.

Both total and dissolved phosphorus analyses were made in the Michigan waters of Lake Erie by the FWPCA Detroit River Enforcement Project. Those analyses showed an average concentration of 0.093 mg/l of total phosphorus and an average concentration of 0.053 mg/l of soluble phosphorus. The Bureau of Commercial Fisheries (Carr, personal communication, 1967), in a study of central basin waters off Lorain, Ohio in 1966, showed a total phosphorus average of 0.016 mg/l and a soluble phosphorus average of 0.006 mg/l. Data from the Ontario Water Resources Commission (Steggles, personal communication, 1965) indicate that of the total phosphorus discharged via the Grand River (Ontario), 56 percent was soluble at the time of survey. It appears then, in mid-lake, the proportion of total to dissolved phosphates is much greater, even though the concentrations are much less.

Analyses for total phosphorus at the National Water Quality Network station at the Buffalo water intake show concentrations of about 0.1 mg/l (Table 24). The values are reported to the nearest 0.1 mg/l. It is likely that if they were reported to the nearest 0.01 mg/l, the phosphorus levels would be something less than 0.1 mg/l.

NITROGEN

Nitrogen in Lake Erie is similar to phosphorus in that its effect on water quality is felt in its nutritional stimulus to plant growth. Under isothermal conditions, it is not a factor of importance in water supplies, however, during summer stratification, where water intakes are located beneath the thermocline, ammonia concentrations assume proportions where large increases in raw water chlorine demand must be satisfied.

Total nitrogen includes all forms, organic and inorganic found in water. Organic nitrogen is unavailable as a nutrient until it is oxidized to the inorganic forms.

The inorganic forms of nitrogen are elemental nitrogen, ammonia nitrogen (NH_3), nitrate nitrogen (NO_3), and nitrite nitrogen (NO_2). The

TABLE 24

CHEMICAL ANALYSES
National Water Quality Network Stations

STATE NEW YORK
MAJOR BASIN NORTHEAST
MINOR BASIN LAKE ERIE-NIAGARA RIVER
STATION LOCATION LAKE ERIE AT
BUFFALO, NEW YORK

DATE OF SAMPLE			TEMP. (Degrees Centigrade)	DISSOLVED OXYGEN mg/l	pH	B.O.D. mg/l	C.O.D. mg/l	CHLORINE DEMAND		AMMONIA-NITROGEN mg/l	CHLORIDES mg/l	ALKALINITY mg/l	HARDNESS mg/l	COLOR (scale units)	TURBIDITY (scale units)	SULFATES mg/l	PHOSPHATES mg/l	TOTAL DISSOLVED SOLIDS mg/l	COLIFORMS per 100 ml
MONTH	DAY	YEAR						1-HOUR mg/l	24-HOUR mg/l										
10	3	62	12.0	9.4	8.4	3.1	5	.9	2.8	.0	23	88	136	0	6	21	.1	223	*40
10	10	62	18.0	8.9	8.3	1.3	15	.6	1.4	.0	23	88	134	0	5	24	.1	254	*40
10	17	62	17.0	9.0	8.3	1.1	14	.9	1.7	.0	23	88	130	0	10	25	.1	192	43
10	24	62	14.5	9.3	8.2	2.6	14	.9	1.6	.0	20	88	138	0	14	27	.1	190	40
10	31	62	12.0	10.0	8.2	2.0	15	.9	1.8	.0	23	88	140	0	20	26	.1	207	24
11	8	62	10.5	10.0	8.2	1.5	10	1.2	2.6	.0	23	88	128	0	8	28	.1	180	60
11	14	62	10.0	10.8	8.2	1.7	12	.9	1.9	.0	23	86	140	0	7	20	.1	187	*4
11	21	62	10.0	11.0	8.2	2.2	16	.8	-	.0	23	88	138	0	12	20	.1	186	20
11	28	62	9.5	11.2	8.1	1.8	13	.6	1.8	.0	23	86	142	0	9	20	.1	193	*4
12	5	62	10.0	11.2	8.2	1.1	10	.8	1.1	.0	23	86	134	0	5	20	.1	185	10
1	2	63	11.0	14.0	8.1	1.8	10	.8	1.9	.0	23	88	138	0	33	21	.1	205	*4
1	9	63	5.0	13.5	-	1.5	11	.4	1.6	.0	23	88	136	0	12	21	.1	179	-
1	16	63	2.0	13.4	8.0	1.8	9	.5	1.9	.0	23	88	138	0	12	21	.1	188	*4
1	23	63	.0	13.5	8.2	1.2	12	.1	1.7	.0	23	90	128	0	11	21	.1	197	-
1	30	63	2.0	13.0	8.0	2.0	16	.4	1.7	.0	23	92	136	0	15	21	.1	189	-
2	6	63	2.5	13.5	8.2	1.7	16	.2	1.2	.0	23	88	132	0	9	20	.1	197	-
2	13	63	3.0	13.6	8.1	1.0	15	.2	1.6	-	23	90	134	0	7	20	.0	194	-
2	20	63	3.0	13.7	8.1	1.6	14	.8	2.2	.0	23	80	130	0	6	20	.1	190	*4
2	27	63	3.0	13.0	8.0	1.5	14	1.4	2.8	.0	23	90	134	0	7	20	.1	189	*10
3	6	63	3.0	13.5	8.1	1.1	14	1.4	3.0	.0	23	86	132	0	4	22	.1	197	*4
3	12	63	3.0	13.5	8.0	1.1	13	1.4	2.4	.0	23	92	134	0	14	22	.1	185	20
3	20	63	4.0	13.5	8.0	1.9	141	.8	2.2	.0	23	90	136	0	7	21	.1	201	*10
3	27	63	3.0	13.6	8.0	3.9	14	1.4	2.4	.0	23	88	138	0	7	22	.1	183	*40
4	3	63	4.0	13.4	8.1	1.2	11	.8	1.8	.0	23	84	132	0	10	20	.1	211	20
4	10	63	4.0	13.0	8.4	1.0	15	.4	1.2	.0	20	88	132	0	9	22	.1	180	*4
4	17	63	4.0	13.0	8.1	1.5	11	.6	1.8	.0	20	84	126	0	15	20	.1	175	20
4	24	63	5.0	14.0	8.2	1.7	11	.8	2.0	.0	23	86	136	0	5	20	.1	157	10
5	1	63	9.0	12.8	7.9	3.1	15	.8	1.2	.0	20	72	120	0	10	20	.1	156	*4
5	8	63	9.0	12.0	8.1	2.2	5	.8	2.2	.0	18	80	120	0	0	20	.1	184	-
5	15	63	10.0	12.2	8.2	2.0	18	.6	1.8	.0	23	80	132	0	10	20	.1	174	-
5	22	63	12.0	11.2	8.2	1.9	18	.8	1.8	.0	23	80	134	0	11	20	.1	197	20
5	29	63	13.0	11.8	8.4	2.2	17	.9	-	-	23	84	126	0	9	21	.1	197	64
6	4	63	19.5	11.5	8.5	2.1	15	.9	2.1	-	23	86	124	0	3	22	.1	194	-
6	12	63	18.0	9.0	8.3	2.0	17	1.6	4.0	.0	23	80	126	0	15	21	.1	185	-
6	19	63	20.0	9.5	8.5	2.8	14	.9	2.9	.0	23	84	126	0	15	20	.1	187	*4
7	3	63	25.0	8.0	8.4	2.5	7	.8	-	.0	20	84	128	0	40	20	.1	214	10
7	10	63	22.5	9.0	8.2	2.0	11	.9	2.2	-	23	86	124	0	5	21	.1	194	-
7	11	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*4
7	17	63	23.0	8.0	8.4	.8	9	.7	2.7	.0	23	84	124	0	7	21	.0	169	50

nitrogen cycle includes all these forms. The chemical and biological condition of the water gives rise to considerable variations in levels of each form present.

For the periods of the 1963 and 1964 surveys the total nitrogen content of the western basin averaged 0.71 mg/l and varied from 0.17 to 2.66 mg/l (Table 25 and Figure 44). In the central basin and the eastern basin, the levels were nearly identical with averages of 0.43 and 0.42 mg/l, respectively. The extremes were 0.10 and 1.30 mg/l. Figure 47 shows the total nitrogen distribution in the western basin for one cruise in September 1964.

Nitrite nitrogen and elemental nitrogen are not significant in the waters of Lake Erie since the oxidation-reduction potential is such to discourage duration of these forms. Ammonia nitrogen, for the periods of survey, averaged 0.159 mg/l in the western basin water and ranged from 0.01 to 9.77 mg/l (Table 26). In the central basin the average was 0.086 mg/l with a range of 0.00 to 0.39 mg/l. The eastern basin average was identical to that of the central basin and the range was nearly so, 0.00 to 0.32 mg/l.

Nitrate nitrogen averaged 0.124 mg/l in the western basin with a range of 0.02 to 1.50 mg/l (Table 27). In the central and eastern basins the averages were identical at 0.090 mg/l. The range in the central basin was 0.01 to 0.50 mg/l while in the eastern basin it was 0.01 to 0.85 mg/l.

Organic nitrogen averaged 0.36 mg/l in the western basin, 0.25 in the central basin, and 0.24 in the eastern basin (Table 28).

Nearshore areas, especially harbors, show widely varying nitrogen concentrations in all three measured forms. In the western basin, values approximately double the mid-lake concentrations, whereas in the central and eastern basins, the values are only slightly higher, on the average, than mid-lake (Table 29).

OTHER CHEMICAL CONSTITUENTS OF LAKE ERIE WATER

Analyses have been made for several metals in western basin water where concentrations exceed those in the remainder of the lake. Table 30 shows the acceptable limits listed in the 1962 U. S. Public Health Service Drinking Water Standards and the concentrations in western basin water for the listed metals.

TABLE 30

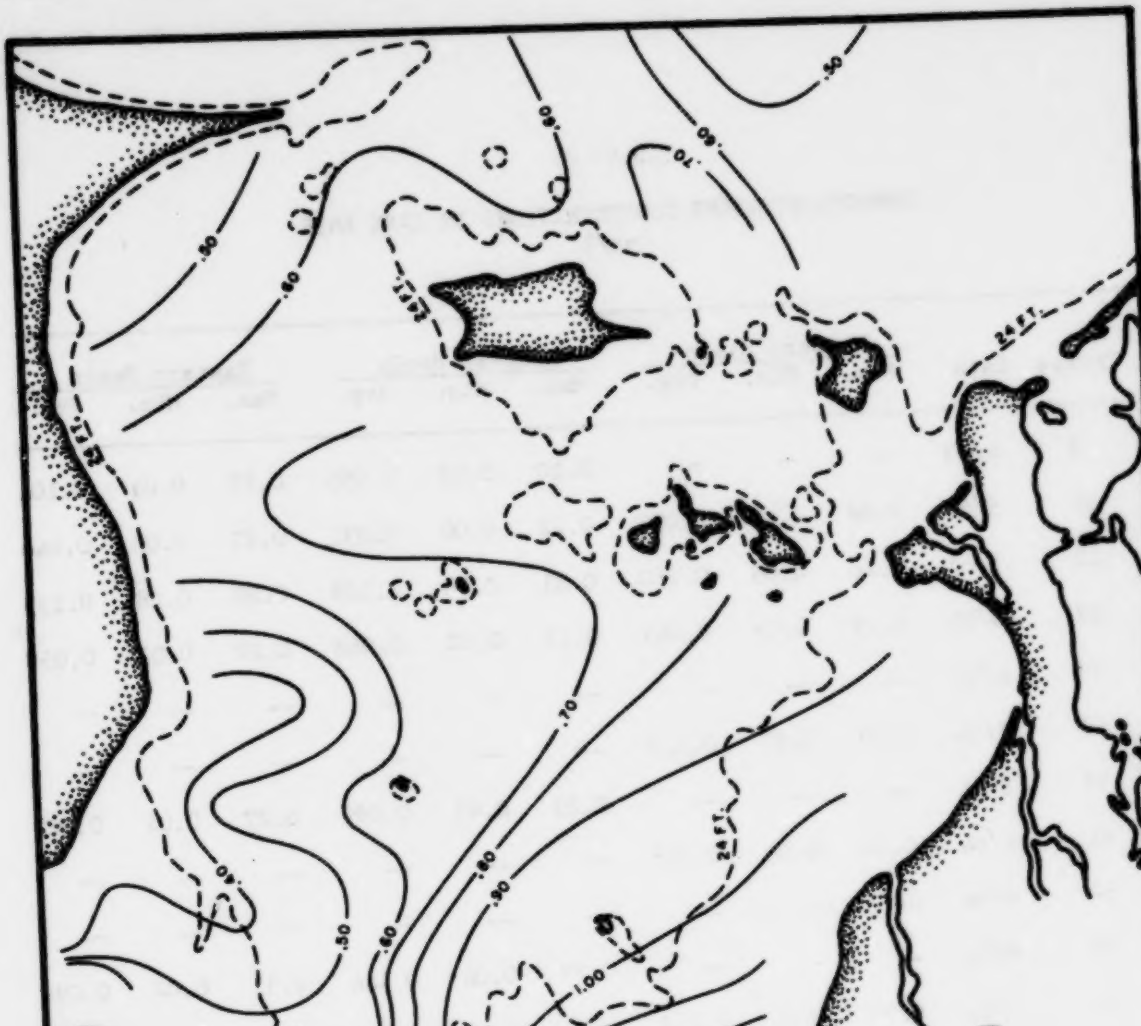
Substance	U.S. PHS Limit (mg/l)	Concentration Western Basin (mg/l)
Zinc	5.0	.00-.23
Copper	1.0	<.001
Cadmium	0.01	<.001
Nickel	--	<.001
Lead	0.05	<.001
Chromium	0.05	<.001

TABLE 25

TOTAL NITROGEN CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	0.68	0.13	0.47	1.16	0.10	0.41
40	5/63	0.67	0.53	0.59	0.93	0.07	0.33	0.75	0.13	0.32
42	6/63	0.71	0.60	0.65	1.09	0.26	0.42	0.61	0.20	0.39
52	10/63	0.72	0.31	0.50	0.89	0.18	0.45	0.80	0.23	0.46
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	2.02	0.25	0.90	--	--	--	--	--	--
58	5/64	--	--	--	1.30	0.12	0.42	1.18	0.17	0.45
61	6/64	2.66	0.17	0.76	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	0.83	0.20	0.50	1.00	0.21	0.47
67	9/64	2.30	0.20	0.86	--	--	--	--	--	--
Avg.				0.71			0.43			0.42

Michigan waters of Lake Erie not included.


.50
.60
.70
.80
.90
1.00
1.10
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1.30
1.40
1.50
1.80
.40
24 FT.
SCALE
0
5
10
N

TOTAL NITROGEN
IN
LAKE ERIE - WESTERN BASIN
SEPTEMBER 9-16, 1964
CONTOUR INTERVAL .10 mg/l

FIGURE 47

TABLE 26

AMMONIA NITROGEN CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	0.10	0.02	0.055	0.32	0.01	0.104
40	5/63	0.09	0.04	0.055	0.11	0.00	0.031	0.27	0.00	0.046
42	6/63	0.26	0.09	0.160	0.23	0.06	0.128	0.29	0.08	0.135
52	10/63	0.19	0.03	0.083	0.17	0.02	0.068	0.22	0.02	0.058
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	0.23	0.07	0.143	--	--	--	--	--	--
58	5/64	--	--	--	0.23	0.01	0.089	0.27	0.01	0.082
61	6/64	0.60	0.04	0.256	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	0.39	0.04	0.144	0.31	0.02	0.094
67	9/64	0.77	0.01	0.258	--	--	--	--	--	--
Avg.				0.159			0.086			0.086

Michigan waters of Lake Erie not included.

TABLE 27

NITRATE NITROGEN CONCENTRATIONS IN LAKE ERIE
mg/l

		Western Basin			Central Basin			Eastern Basin		
Cruise	Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	0.13	0.02	0.052	0.06	0.01	0.019
40	5/63	0.25	0.02	0.113	0.13	0.02	0.047	0.17	0.02	0.039
42	6/63	0.06	0.02	0.040	0.84	0.02	0.063	0.03	0.01	0.018
52	10/63	0.29	0.09	0.157	0.42	0.03	0.111	0.47	0.01	0.091
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	--	--	--	--	--	--	--	--	--
58	5/64	--	--	--	0.50	0.00	0.121	0.52	0.06	0.207
61	6/64	1.50	0.03	0.287	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	0.36	0.01	0.146	0.85	0.07	0.164
67	9/64	0.54	0.02	0.148	--	--	--	--	--	--
Avg.				0.124			0.090			0.090

Michigan waters of Lake Erie not included.

TABLE 28

ORGANIC NITROGEN CONCENTRATIONS IN LAKE ERIE
mg/l

Cruise	Date	Western Basin			Central Basin			Eastern Basin		
		Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
9	4/63	--	--	--	--	--	0.36	--	--	0.29
40	5/63	--	--	0.42	--	--	0.25	--	--	0.24
42	6/63	--	--	0.45	--	--	0.23	--	--	0.24
52	10/63	--	--	0.26	--	--	0.27	--	--	0.31
55	4/64	--	--	--	--	--	--	--	--	--
57	5/64	--	--	--	--	--	--	--	--	--
58	5/64	--	--	--	--	--	0.21	--	--	0.16
61	6/64	--	--	0.21	--	--	--	--	--	--
62	6/64	--	--	--	--	--	--	--	--	--
66	8/64	--	--	--	--	--	0.21	--	--	0.21
67	9/64	--	--	0.45	--	--	--	--	--	--
Avg.				0.36			0.25			0.24

Michigan waters of Lake Erie not included.

TABLE 29

WATER QUALITY-NEARSHORE AND HARBORS
(mg/l or µmhos/cm)

Parameter	Michigan waters of Lake Erie		Maumee Bay		Sandusky Bay		Lorain Harbor		Cleveland Harbor		Fairport Harbor		Ashtabula Harbor		Erie Harbor	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Cond (25°C)			280	460	256	800	300	340	--		330	5920	--		330	360
DS			200	290	190	680	160	230	180	370	180	6000	170	230	180	290
TS			200	350	210	760	170	270	180	680	190	6100	180	250	200	290
Chlor.	27	82	20	32	16	32	19	25	14	88	--		24	42	26	38
Sol PO_4	.05	.20	.02	.19	.02	.17	.02	.11	--		--		.02	.06	.01	.03
SO_4			--		25	256	27	37	--		--		--		26	44
SiO_2			0.6	1.7	0.3	5.9	.40	1.10	--		--		--		.3	.5
K			1.4	2.6	1.2	4.0	1.3	2.2	--		--		--		1.4	1.9
Mg			12	18	10	38	9	11	--		--		--		9	9
Ca			35	42	38	114	34	38	--		--		--		42	47
Na			12	20	10	16	10	13	--		--		--		17	21
ABS	<.025		.05	.15	.05	.20	.05	.15	--		--		--		.07	.14
Alk	78	157	86	120	87	120	83	99	81	130	90	110	94	100	90	96
pH	8.4	9.2	7.4	9.7	7.5	9.1	7.5	8.7	6.7	9.5	7.1	8.7	8.2	8.5	7.3	8.1
Temp			21	25	23	26	24	25	16	21	23	29	15	17	16	19
DO%S			60	95	65	115	80	95	70	95	80	130	95	110	Avg.	60%
BOD			1.5	4.0	2.1	6.3	1.0	2.3	--		--		2.0	5.6	Avg.	3.3
COD			12	53	13	42	10	28	8	22	8	12	7	11	Avg.	24
Phenol	0.0	0.058	--		--		--		--				--			
Total N			.82	3.45	.82	3.50	.50	4.20	--						.66	.80
Org N	0.20	0.30	.07	1.33	.53	2.30	.01	1.10	--				.29	.49	.30	.59
Amm N	0.20	0.30	.30	1.80			.12	.90	--				.03	1.55	.12	.23
Nit N	0.11	0.91	.00	.80	.01	1.80	00	2.90	--						.07	.14

Lake Erie contains no known chemical substances in quantities toxic to aquatic life or sufficient to cause any sort of health hazard to users of the water. This does not apply to tributary waters in highly industrialized areas where concentrations may, under certain conditions, be hazardous. Such areas exist at Detroit, Lorain, Cleveland, Fairport, and Ashtabula.

RADIOCHEMISTRY

Radioactivity is defined as the spontaneous emission of alpha, beta, or other radiation by the disintegration of unstable atomic nuclei. Naturally-occurring, radioactive isotopes usually decay (disintegrate) by stepwise emission of alpha or beta particles to form stable isotopes. An artificially produced radioisotope, however, generally decays in a single step by the emission of a beta particle.

Alpha and beta particles have the ability to ionize any matter with which they interact by the production of ion-pairs. It is the formation of such ion-pairs in biological tissue that results in cell destruction, impairment, or mutation.

Radioactive wastes discharged to the environment are not absorbed in harmless fashion. Even though decay and dilution may occur, radionuclides may be concentrated physically, chemically, and/or through biological assimilation and retention. As a result the radionuclide concentration will increase as it passes through the environment to the point of human contact.

Human exposure to radioactively contaminated surface water can result when the surface water is used as a public water supply. In addition, biologically concentrated radioactivity can be assimilated through the ingestion of fish and other aquatic life.

Prior to cessation of atmospheric nuclear testing, fallout was the most significant source of radioactive pollution to Lake Erie. Other possible sources are the atmospheric and drainage discharges of reactor plants and of licensed radioisotope users in the basin.

ALPHA ACTIVITY OF LAKE WATER SAMPLES

The annual mean concentrations of alpha radioactivity in suspended and dissolved solids observed in samples from Lake Erie were 0.6 and 1.6 pc/l, respectively, for 1963.

The highest averages and maxima in 1963 occurred near the mouth of the Black River where the suspended solids mean and maximum were 1.5 and 4.6 pc/l, respectively; and the dissolved solids mean and maximum were 5.2 and 12 pc/l, respectively.

All 1964 averages were low in alpha activity with none exceeding 5.3 pc/l.

BETA ACTIVITY OF LAKE WATER

All suspended solids average beta activities were low for both 1963 and 1964. The 1963 means ranged from 8.9 to 18 pc/l with a weighted mean of 14 pc/l; the 1964 mean, however, ranged from 3.9 to 9.5 pc/l with a weighted mean of 7.9 pc/l.

ALPHA ACTIVITY OF PLANKTON SAMPLES

The gross alpha radioactivity in plankton samples was less than one to 30 pc/gram of ashed weight for 1963 with a mean value of 8.3 pc/gram, and from less than one to 20 pc/gram with a mean of 8.7 pc/gram for 1964. These ranges and means are essentially the same. The radioactivity levels (both alpha and beta) in plankton are higher than in water due to the concentrating effect of biological materials. Published work (Williams, Swanson) has shown the effectiveness of Euglena and Chlorella in decontaminating water of cesium 137. In 6-days Euglena reduced the degree of contamination 69 percent - 96 percent in 34 days.

Since alpha activity is usually associated with naturally occurring radioisotopes, and such isotopes, being of high atomic number, seldom appear as components of plankton, low alpha activities for plankton can be expected.

BETA ACTIVITY OF PLANKTON SAMPLES

Gross beta values range from 33 to 1200 pc/gram with a mean of 160 pc/gram for 1963, and from 76 to 400 pc/gram with a mean of 190 pc/gram for 1964. The ranges are similar except for the value of 1200 pc/gram which came from a sample collected off the tip of Long Point toward the east end of the lake.

CHAPTER 4

LAKE ERIE BIOLOGICAL CHARACTERISTICS

Aquatic biological life is sensitive to physical and chemical changes in its environment. Biological effects are often relatively extreme, and for this reason, the aquatic community is an excellent indicator of water quality. The important considerations are the total population, types, and relative numbers of each type. Pristine water and its bottom sediment contain a low total population, many types, and low numbers of each type. As water is degraded, the total population increases, the number of types decrease, and the numbers of a few resistant types increase greatly.

The total numbers increase because of increased nutrient content in the water. Organisms which more readily take advantage of high nutrient content and organic sediments begin to predominate. Bottom organisms which can withstand extended periods with little or no oxygen may replace those requiring an abundant oxygen supply. Plankton and fish populations change to those which are less desirable from a human standpoint. Plankton may cause taste and odor problems in water supplies and the clogging of intakes and filters. "Rough" fish may replace those prized for their edibility.

Lake Erie is presently experiencing rather dramatic changes in its biological productivity. These changes are not at the natural sequence rate, and can be related directly to man's activities.

LAKE BOTTOM BIOLOGY

The benthic fauna are minute animals which live on and within the lake bottom sediments. Some have been classified, rather non-precisely, as "pollution-tolerant" or "pollution-sensitive". This classification rests on the ability of an organism to withstand periods of deficiency or absence of dissolved oxygen and does not imply that some organisms might prefer a lack of oxygen. Accordingly, these terms will be used in the following narrative.

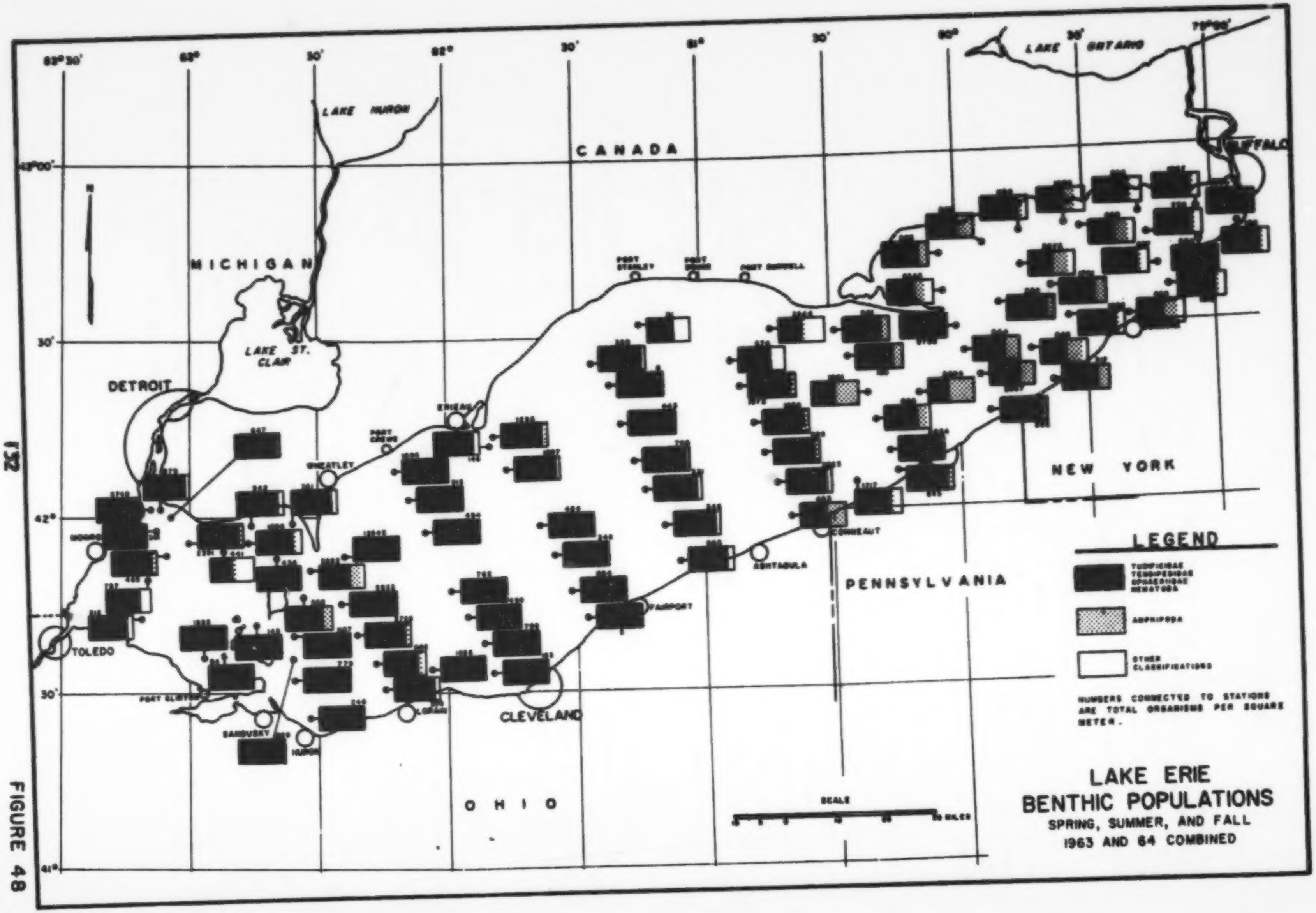
Studies conducted by the U. S. Bureau of Commercial Fisheries between 1929 and 1959 (Beeton, 1961 and Wright, 1955) and personnel at the Franz Theodore Stone Institute of Hydrobiology (Britt, 1955 a and b) show significant changes in population, type, and habitat of bottom-dwelling organisms in western Lake Erie. Pollution-tolerant forms have increased greatly along the west side of the basin and in the island area. These include Tubificidae, Sphaeriidae, and Tendipedidae. As an example in the island area, Tubificidae have increased from 10 organisms per square meter in 1929 to 550 organisms per square meter in 1957. During the same period Tendipedidae increased from 60 to 300 organisms per square meter. The Sphaeriidae showed a three-fold increase at two index stations near South Bass Island.

The pollution-sensitive caddis fly larvae (Tricoptera) and the mayfly (Hexagenia spp.) have been drastically reduced in numbers. Beeton (1961) reported that the formerly abundant Tricoptera larvae averaged less than one per square meter in 1957. The burrowing mayfly nymph, which lives in soft mud and feeds on detritus, was the most common macroinvertebrate in the western basin prior to the early 1950's. Wright (1955) found 285 and 510 nymphs per square meter in 1929 and 1930, respectively, in the island area. Chandler (1963) summarized studies made between 1942 and 1947 and reported an average of 350 nymphs per square meter for that period. Wood (1963) found an average of 235 per square meter for 204 samples collected in 1951 and 1952. In June 1953 Britt (1955) found approximately 300 nymphs per square meter. After sampling again in September following a five-day period of thermal stratification and bottom oxygen depletion Britt found only 44 nymphs per square meter. The succeeding year showed a good recovery but Beeton in 1959 found only 39 per square meter. In June 1964 the U. S. Public Health Service found only two nymphs in samples from 47 island area sites. None were found in the Michigan waters of the basin.

Published quantitative data are not available on the bottom fauna of central and eastern Lake Erie. Newspaper articles, dating back to 1927 describe "immense swarms" of mayflies blown into the city of Cleveland. A decline was first noted in 1949 but they reappeared in 1950 and were reported yearly through 1957. They were not reported after 1958.

Ferguson (personal communication), on a transect between Port Burwell and Conneaut in the spring and summer of 1958, showed populations of Tubificidae, Tendipedidae, Sphaeriidae, Amphipoda, Tricoptera, and Gastropoda. Gut contents of blue pike demonstrated that the pollution-sensitive Tricoptera and Amphipoda were common food.

The results of bottom fauna surveys of Lake Erie by the U. S. Public Health Service in 1963 and 1964 are summarized in Figure 48. It shows the relative abundance of the pollution-sensitive scud to the more tolerant sludgeworms, bloodworms, fingernail clams and nematodes. Figure 49 divides the lake into four zones based on the benthic fauna populations. It is evident that most of the western and central basins were characterized by the lack of pollution-sensitive scud and preponderance of pollution-tolerant species of sludgeworms, bloodworms, fingernail clams, and nematodes. A few areas in the western basin, the


LAKE HURON
LAKE ONTARIO
CANADA
MICHIGAN
LAKE ST. CLAIR
DETROIT
TOLEDO
PORT CLINTON
SANDUSKY
HURON
LORAIN
CLEVELAND
FAIRPORT
ASHTABULA
CONNEAUT
WHEATLEY
ERIEAU
PORT STANLEY
PORT BURWELL
PORT DOVER
BUFFALO
NEW YORK
PENNSYLVANIA
OHIO
83°30'
83°
30'
82°
81°
80°
79°00'
43°00'
42°
41°
N
LEGEND
TUBIFICIDAE
TENDIPEDIDAE
SPHAERIIDAE
NEMATODA
AMPHIPODA
OTHER CLASSIFICATIONS
NUMBERS CONNECTED TO STATIONS ARE TOTAL ORGANISMS PER SQUARE METER.
SCALE
20 MILES

LAKE ERIE
BENTHIC POPULATIONS
SPRING, SUMMER, AND FALL
1963 AND 64 COMBINED

FIGURE 48

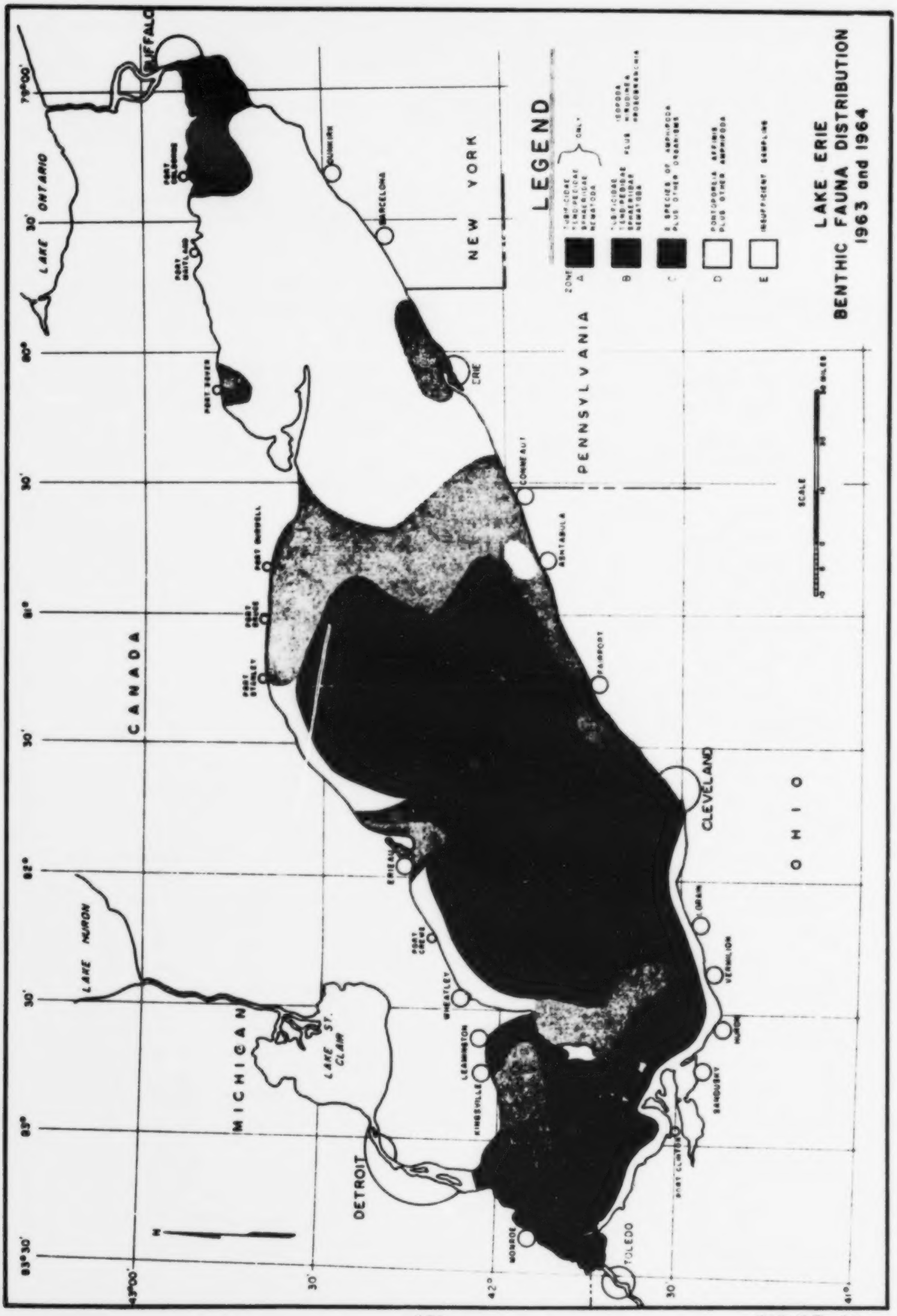

LAKE ERIE
BENTHIC FAUNA DISTRIBUTION
1963 and 1964
LEGEND
ZONE A TUBIFICIDAE TENDIPEDIDAE SPHAERIIDAE NEMATODA ONLY
B TUBIFICIDAE TENDIPEDIDAE SPHAERIIDAE NEMATODA PLUS ISOPODA HIRUDINEA PROSOBRANCHIA
C 2 SPECIES OF AMPHIPODA PLUS OTHER ORGANISMS
D PONTOPOREIA AFFINIS PLUS OTHER AMPHIPODA
E INSUFFICIENT SAMPLING
SCALE
MILES
LAKE ONTARIO
BUFFALO
NEW YORK
PENNSYLVANIA
OHIO
CANADA
MICHIGAN
LAKE HURON
LAKE ST. CLAIR
DETROIT
TOLEDO
MONROE
PORT CLINTON
SANDUSKY
HURON
VERMILION
LORAIN
CLEVELAND
FAIRPORT
ASHTABULA
CONNEAUT
ERIE
BARCELONA
DUNKIRK
PORT COLBORNE
PORT MAITLAND
PORT DOVER
PORT BURWELL
PORT BRUCE
PORT STANLEY
ERIEAU
PORT CREWS
WHEATLEY
LEAMINGTON
KINGSVILLE
83°30'
83°
30'
82°
30'
81°
30'
80°
30'
79°00'
43°00'
30'
42°
30'
41°
N

FIGURE 49

eastern part of the central basin, and the eastern basin support a good population of pollution-sensitive scud and are indicative of the more favorable environmental conditions in these areas. The four zones shown in Figure 49 are described as follows:

Zona A - Contains only the pollution-tolerant groups, sludgeworms, fingernail clams, nematodes, and pollution-tolerant species of bloodworms.

Zone B - In addition to groups in Zone A, the following groups of intermediate tolerance were found: aquatic sowbugs, snails, leeches, and several additional species of bloodworms.

Zone C - May contain any organisms found in Zones A and B but the two species of scuds (*Gammarus fasciatus* and/or *Hyalella azteca*) are always present.

Zone D - May contain any group of organisms listed in Zones A, B, and C but always contains the intolerant scud (*Pontoporeia affinis*).

Zones C and D had the greatest variety of bottom-dwelling organisms and were characterized by the presence of scuds at each station. *Gammarus fasciatus* was found regardless of bottom type and *Hyalella azteca* was present at many locations associated with a sand, gravel, or rock bottom. *Pontoporeia affinis* which requires cold, deep, clear, and well-oxygenated water occurred only in Zone D.

The variety of bloodworms is also important. All lakes have a variety of bloodworm (midge) larvae as part of the benthic fauna, and their habitats vary according to the quality of the overlying water. Curry (Unpublished) classified the larvae according to one of four categories depending upon their environmental requirements. The categories (1) Pollution-tolerant, (2) Cosmopolitan, (3) Clean-Water, and (4) Others, adequately covered the 38 species identified in Lake Erie.

The Pollution-tolerant species include larvae existing even for a short period of time in habitats having sediments with a high percentage of organic matter, low dissolved oxygen, rather high temperatures, and possible septic conditions. The Clean Water species included larvae that were found in the colder, deeper waters of oligotrophic lakes and streams. In these areas the temperatures were lower, dissolved oxygen high, and septic conditions were never present. Larvae classified as Cosmopolitan species were found in both pollution-tolerant and clean-water environments. The Other species group included larval forms found only occasionally in any bottom samples. Usually these larvae were restricted to isolated regions of the lake. This could be due to one or more factors including depth, temperature, food, carbon dioxide, or oxygen.

Of the 38 identified species in the lake, 54 percent were Pollution-Tolerant, 43 percent Cosmopolitan, 1 percent Clean Water, and 2 percent Other. The population of bloodworm larvae inhabiting the central portion of Zone A was composed of 80 percent Pollution-Tolerant species. Zone A is also the area that contained the fewest number of species of bloodworm larvae. Curry, in unpublished data, gives a more detailed treatment of the bloodworm distribution data.

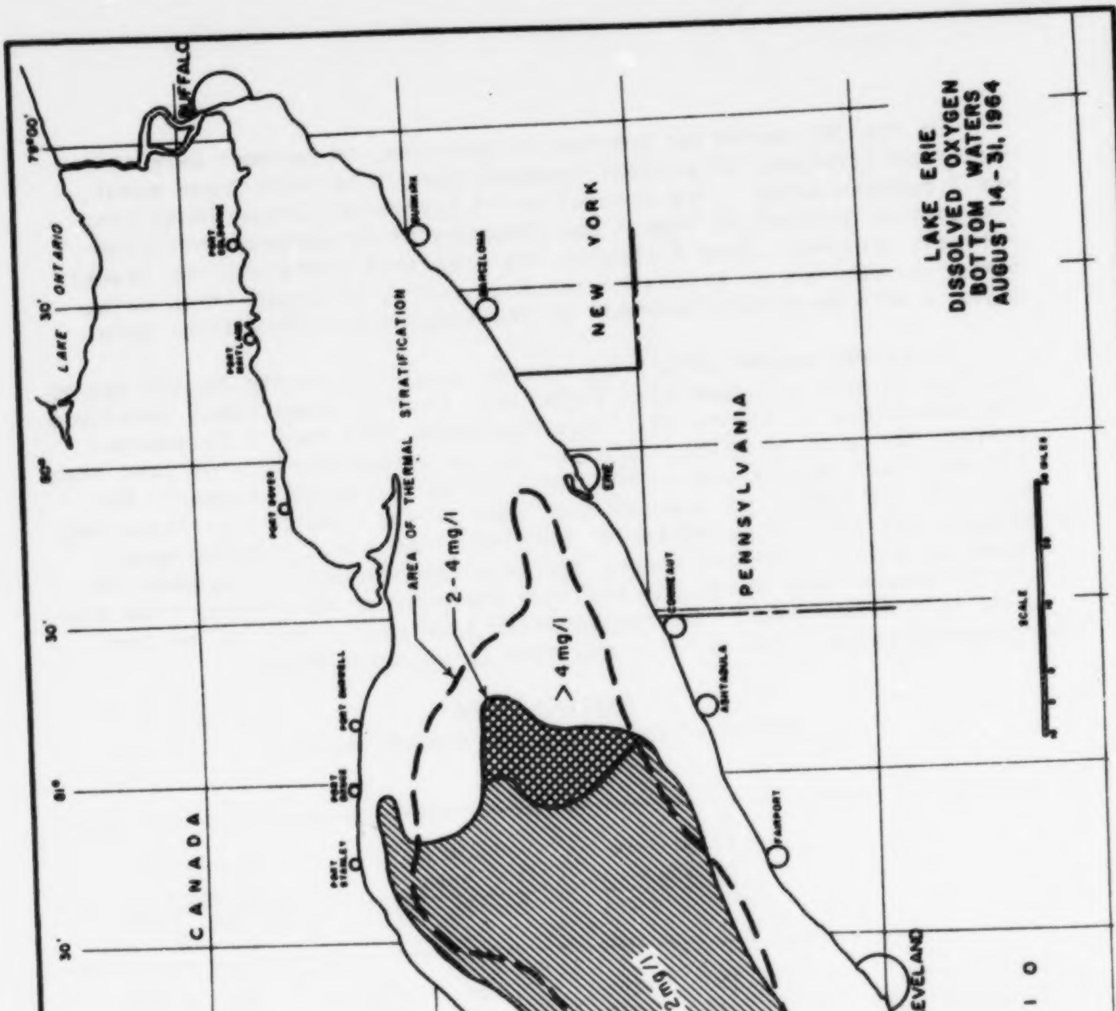
Dissolved oxygen data from studies conducted by the Public Health Service, Bureau of Commercial Fisheries, and the Great Lakes Institute are summarized in Figure 50. This map shows that Zone A is approximately the area in which dissolved oxygen concentrations of less than 2.0 mg/l have been found in the hypolimnion during the summer. Not only was the number of species much less in the area of low dissolved oxygen, but the following table indicates that total numbers were lower as well. Stations chosen for this comparison were between 13 and 22 meters deep where a persistent thermocline is present from mid-June to mid-September. Bottom deposits were mostly mud in the low dissolved oxygen area and mud and sand in adjacent areas.

BENTHIC FAUNA
Number of Organisms per square meter

	West of Low DO area		Low DO Area		East of Low DO area	
	Spring	Fall	Spring	Fall	Spring	Fall
Tubificidae	1,850	1,830	186	1,460	354	2,300
Tendipedidae	47	407	39	156	107	278
Sphaeriidae	350	502	187	137	162	307
Amphipoda	1	7	0	0	69	465
Other	121	145	26	31	73	221
Total	2,369	2,891	438	1,784	765	3,571

The dissolved oxygen deficit not only limits the number of species but limits the total numbers as well, even though the sediments are higher in organic matter.

Zone B is a transition area where the pollution-intolerant scuds, mayflies, unionid clams, and caddis flies were absent. Intermediately tolerant forms such as the aquatic sowbug (Asellus militaris), snail (Gastropoda), and leech (mostly Helobdella sp.) were found. Zone B approximates the area where dissolved oxygen was between 2.0 and 4.0 mg/l in the hypolimnion during the summer of 1964.



LAKE ONTARIO
BUFFALO
DUNKIRK
BARCELONA
NEW YORK
PENNSYLVANIA
ERIE
CONNEAUT
ASHTABULA
FAIRPORT
CLEVELAND
OHIO
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
TOLEDO
MONROE
DETROIT
MICHIGAN
LAKE ST. CLAIR
LAKE HURON
CANADA
KINGSVILLE
LEAMINGTON
WHEATLEY
ERIEAU
PORT STANLEY
PORT BRUCE
PORT BURWELL
PORT DOVER
PORT MAITLAND
PORT COLBORNE
AREA OF THERMAL STRATIFICATION
2 - 4 mg/l
> 4 mg/l
0 - 2 mg/l
SCALE
79°00'
30'
80°
30'
81°
30'
82°
30'
83°
83°30'
43°00'
30'
42°
30'
41°
N

LAKE ERIE
DISSOLVED OXYGEN
BOTTOM WATERS
AUGUST 14 - 31, 1964

FIGURE 50

The distribution of the mayfly nymph (Hexagenia spp.) is difficult to plot graphically because of erratic occurrence. This genus can apparently survive only a short time when dissolved oxygen in the water is less than 4.0 mg/l and water temperature relatively high. The genus rarely occurs in water deeper than 50 feet, and since it requires a soft bottom its absence cannot always be attributed to poor water quality. Data from inshore stations where bottom type and depth were suitable for Hexagenia spp. showed the nymph was absent along the south shore except at one station northeast of Ashtabula. Hexagenia was abundant at all stations in Long Point Bay and in small numbers at most suitable locations near the Canadian shore of the eastern basin. A few Hexagenia spp. nymphs were found near the Canadian shore at the mouth of the Detroit River in 15 feet of water and near Colchester and Kingsville, Ontario.

A special study was conducted in the island area of Lake Erie in June 1964, to determine Hexagenia populations where they were formerly the most abundant macroinvertebrate inhabiting the bottom. The entire island area was sampled at 47 stations and only two nymphs were found. The bottom dwelling animals, except in shallow rocky areas, were predominately sludgeworms, bloodworms, and fingernail clams with only a few unionid clams and snails.

LAKE WATER BIOLOGY

ALGAE

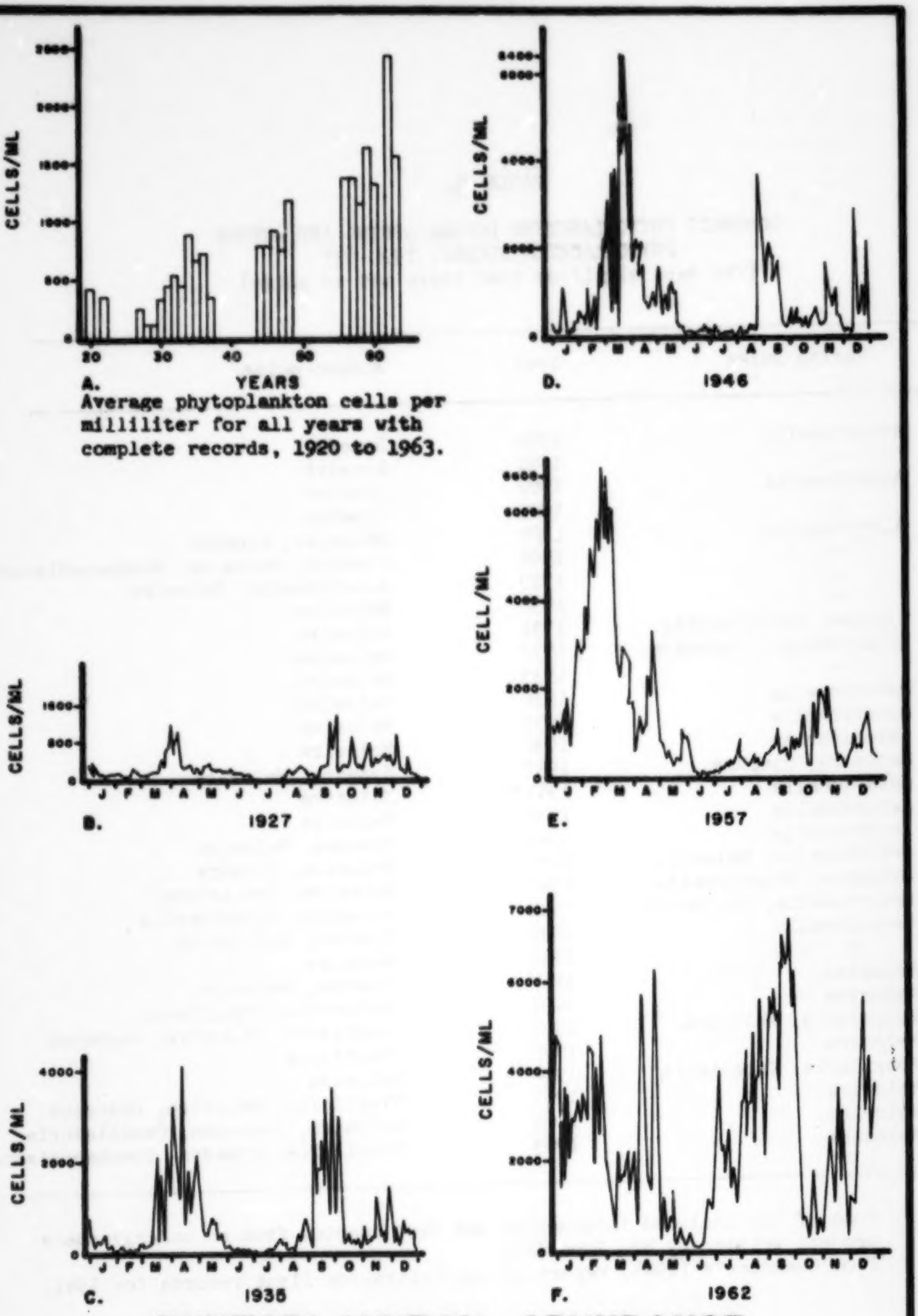
Algae are indicators of water quality. Increases in total productivity and decreasing variety indicate degradation resulting from increased nutrient content in the water.

Increases in productivity of both phytoplankton and the filamentous green alga, Cladophora sp., have been noted in the literature. Nuisance growths of Cladophora have been reported for many years in the island area (Langlois, 1954). However, in recent years island residents report the problem has become worse. Reports indicate that Cladophora nuisance problems have also increased on beaches around Erie, Pennsylvania and on New York beaches in the last several years. Neil and Owen (1964) report many Canadian beaches are also experiencing increased problems.

Chandler (1940, 1944) and Chandler and Weeks (1945) evaluated extensive phytoplankton, chemical, and physical data collected between 1938 and 1942 around the Bass Islands. It was concluded that phytoplankton populations were highly variable from year to year and that phytoplankton productivity based on only one year could be misleading. Chandler and Weeks believed these variations to be related to physical changes such as temperature, turbidity, and solar radiation rather than chemical changes. During the study period, diatoms never comprised less than 27 percent of the total, and total numbers never exceeded 1,000,000 units per liter. Blue-green algae were rarely predominant and never exceeded 52 percent of the total. Generally, the predominant spring genera were *Synedra*, *Asterionella*, *Fragilaria*, *Tabellaria*, and *Cyclotella*. Casper (1965) indicated that productivity had increased significantly and species composition changed to a great degree since 1942. Samples collected around the island area in September 1964 gave total counts of up to 3,500,000 units per liter with blue-greens comprising 70 percent of the total. Samples collected in April 1964 also yielded higher counts than any reported during the 1938-1942 study.

Davis (1964) has summarized plankton data accumulated by the Cleveland Division Avenue Filtration Plant since 1919. Although yearly variations are large, a definite long-term increase in plankton productivity is apparent as shown in Figure 51. The data show that plankton counts have increased from a yearly average of 200-400 cells/ml between 1920 and 1930 to a current average of 1,500-2,300 cells/ml. This indicates an increase in algal concentration of between 500 and 700 percent in the Cleveland area. The data also indicate an increase in duration of pulses. A pulse is a profusion of algae at a certain period of the year. Comparing the phytoplankton abundance between 1927 and 1962, Figure 51F, the increase in duration is very apparent. The spring and autumn pulses in 1927 occurred from March to April and from late August to mid-September, respectively. In 1962, the spring and autumn pulses occurred from mid-February to mid-April and from mid-June to mid-September, respectively. Correspondingly, the lows are now shorter in duration and numbers of phytoplankton per milliliter have increased considerably. There has also been a significant change in dominant genera of the spring and autumn phytoplankton pulse as indicated in Table 31. The dominant spring genera have changed from *Asterionella* to *Melosira*. A corresponding shift in the fall pulse has been from *Synedra* to *Melosira* to *Fragilaria*. During recent years the autumn pulse has shown an increase in importance of green and blue-green algae such as *Pediastrum*, *Anabaena*, and *Oscillatoria* replacing in part the previous dominance by diatoms. Burkholder (1960), in the central and eastern basin in 1928-29 showed that diatoms were the dominant group of phytoplankters during June and July while in August the ratio of diatoms to green and blue-greens decreased. By mid-September, however, the diatoms once again were by far the dominant group. The data also showed that concentrations of phytoplankton never exceeded 2,000 per liter.

During the spring and summer of 1964, U. S. Public Health Service personnel made several visits to the island area of western Lake Erie to determine the extent of *Cladophora* growths. Around the islands, the rocky shorelines and reef areas provide an ideal substrate for *Cladophora* attachment. Under these conditions the major factors influencing abundance are nutrient supply, solar radiation, turbidity, and adequate wave action.



Average phytoplankton cells per milliliter for all years with complete records, 1920 to 1963.

PHYTOPLANKTON ABUNDANCE

LAKE ERIE (CLEVELAND WATER INTAKE RECORDS)

FIGURE 51

TABLE 31

DOMINANT PHYTOPLANKTERS DURING SPRING AND AUTUMN PHYTOPLANKTON PULSES, 1920-63*

(The dash signifies that there was no pulse)

Spring pulse	Year	Autumn pulse
Asterionella	1920	Synedra
--	1921	Synedra
Asterionella	1922	Synedra
--	1923	Synedra
Asterionella	1927	Melosira, Synedra
--	1928	Synedra, Melosira, Stephenodiscus
--	1929	Asterionella, Melosira
--	1930	Melosira
Synedra, Asterionella	1931	Melosira
Asterionella, Melosira	1932	Melosira
--	1933	Melosira
Asterionella	1934	Melosira
Asterionella	1935	Melosira
Asterionella	1936	Melosira
Melosira, Synedra	1937	Synedra, Melosira
Asterionella	1941**	Melosira
Asterionella	1944	Melosira
Asterionella	1945	Synedra, Melosira
Asterionella, Melosira	1946	Melosira, Synedra
Melosira, Asterionella	1947	Melosira, Pediastrum
Asterionella, Cyclotella	1948	Melosira, Asterionella
Asterionella	1949	Synedra, Pediastrum
?	1955	Melosira
Melosira	1956	Synedra, Melosira
Melosira	1957	Pediastrum, Fragilaria
Fragilaria, Melosira	1958	Fragilaria, Melosira, Anabaena
Melosira	1959	Fragilaria
Fragilaria, Tabellaria	1960	Melosira
Melosira	1961	Fragilaria, Melosira, Anabaena
Melosira	1962	Melosira, Anabaena, Oscillatoria
Melosira	1963	Fragilaria, Synedra, Stephanodiscus

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* Some of the included information has been adapted from an undergraduate project written by Mr. John Wolk.

** From Chandler's (1944) report of the Filtration Plant records for 1941.

Around Kelleys Island the water is usually clear and secchi disc readings were 8-12 feet except during heavy phytoplankton blooms when readings of less than two feet were recorded. Observations by scuba divers revealed heavy Cladophora growths extended from the surface to a depth of 11 feet and then gradually decreased until extinction at a depth of 15 feet. At maturity in late June and early July, strands of algae three to six feet in length were common. Growths were heaviest on the east side of Kelleys Island around Gull and Kelleys Island shoals. The more turbid waters around the Bass Islands did not permit adequate light penetration for growths in water depths greater than 5 feet. The investigation detected approximately four square miles covered with luxurious Cladophora growth in the island region alone.

Throughout the island region, and along the shores of Lake Erie, where the conditions are suitable, generally along rocky shores, these heavy growths exist. Upon maturity, wave action, etc., the strands of algae are broken from their attachment enabling wind and currents to deposit the massive quantities of Cladophora on beaches, in harbors, and in deeper waters of the lake. It has also been noted that mats of decomposing algae settle to the bottom in the central basin (Zone A of Figure 49) and become part of the sediment after decomposition.

During interviews, local residents reported that growths have been increasing rapidly in the past 20 years and that each succeeding year was becoming worse. Canada and other communities along the lake shore are experiencing this increasing problem.

It is clear from the literature that phytoplankton productivity in Lake Erie is highly variable from year to year and evaluation of phytoplankton data based on one or two years sampling could be misleading. Extreme care must be taken in comparing data under these conditions. Due to limited phytoplankton analysis from 1963 and 1964 the data will be treated generally to show ranges and to illustrate seasonal variations in productivity and species composition.

The phytoplankton data were averaged from all stations and separated according to basins and seasons. The tables below illustrate differences between diatoms and others which consisted of green and blue-green algae forms for each basin and season.

PHYTOPLANKTON 1963 - 1964
Diatoms vs. Total Number of Organisms
(Percent)

Basin	Diatom - Spring	Diatom - Fall	Total Annual Average
Western	79.2	3.0	8.8
Central	44.4	12.9	27.3
Eastern	49.8	35.4	40.0

PHYTOPLANKTON 1963 - 1964
Greens and Blue-greens vs. Total Number of Organisms
(Percent)

Basin	G-BG - Spring	G-BG - Fall	Total Annual Average
Western	20.8	97.0	91.2
Central	55.6	87.1	72.7
Eastern	50.2	64.6	60.0

The data show a spring pulse composed primarily of diatoms in the western basin, mainly Cyclotella-Stephanodiscus. It is indicated that diatom blooms occur in the western basin during the spring when the dissolved silica content is high. Diatoms assimilate silica in skeletal formation. The spring diatom pulse was also noted in the central and eastern basin but not to the extent of that in the western basin. It was followed by a low level summer population composed mainly of diatoms in the central and eastern basins and greens or blue-greens in the western basin. Due to lack of data, a comparison was not made with the other seasons. In late summer and early fall another pulse developed in which greens and blue-greens were dominant over the entire lake. Greens and blue-greens comprised a much higher proportion of the total population in all basins as indicated by the table of percentages. The following table shows populations and types of algae with reference to basin and season. As expected, the decreasing west to east trend is very pronounced when considering the total averages.

PHYTOPLANKTON
Average Numbers of Organisms per ml

Type of Algae	Season	Basin		
		Western	Central	Eastern
Green Blue-green	Spring	375	650	290
Diatom	Spring	1,430	520	285
Total	Spring	1,805	1,170	575
Green Blue-green	Fall	10,475	875	115
Diatom	Fall	325	130	65
Total	Fall	10,800	1,005	180
Total	Average	8,000	1,100	300

An extensive blue-green and green phytoplankton bloom in western Lake Erie was investigated in September 1964 (Casper, 1965). The bloom, covering approximately 800 square miles, consisted primarily of Oscillatoria sp., Aphanizomenon holsaticum, Anacystis cyonea, and Glenodiniam sp. Average numbers were 28,600 organisms per ml with a maximum of 170,000 organisms per ml. According to residents of the area these massive blooms have been occurring for a number of years but the intensity, frequency, and duration have been increasing.

FISH

The changes in the algal productivity of Lake Erie have been accompanied by changes in the fish populations. As far as man is concerned the changes over the years have been for the worse. Fish desirable for human consumption have declined in abundance (Figure 52) and have been replaced by less desirable species.

Man is responsible for the accelerated eutrophication of Lake Erie with its consequent changes in the quality and quantity of fish present. He catches the desirable fish when available with great efficiency, and returns the less desirable; he directly alters the fish habitat by introducing his wastes to the water and sediment. The resulting turbidity, oxygen depletion, and toxicity have eliminated preferred fish food forcing the desirable fish to vacate and spawn elsewhere. The less desirable species then proliferate since competition for available food has decreased. Unfortunately most of man's activities have been detrimental.

Commercial fish catch statistics, gathered by the U. S. Bureau of Commercial Fisheries, have provided a long record of the relative abundance of desirable fish species in Lake Erie (Tables 32 and 33 and Figure 52). In recent years, continuing surveys have been introduced by federal and state agencies on the reproductive phase of the life cycles of fishes and limited predictions of future populations are now possible.

The sturgeon almost disappeared from catch statistics at about the turn of the century. The cisco, once the dominant species of the commercial catch, experienced a sudden decline in 1926, showed a slight recovery, and declined to insignificance in 1957. Whitefish declined drastically in the commercial catch in 1955. The walleye began a drastic decline in 1957 and is still in great distress. The blue pike, which formerly produced several million pounds per year became nearly extinct in 1958.

The yellow perch has managed to hold its own, but it also shows signs of weakening in the commercial catch. It is the only plentiful fish remaining of the former many prized varieties. The smelt is now commercially exploitable and it, along with yellow perch, is sustaining the fishing industry in Lake Erie.

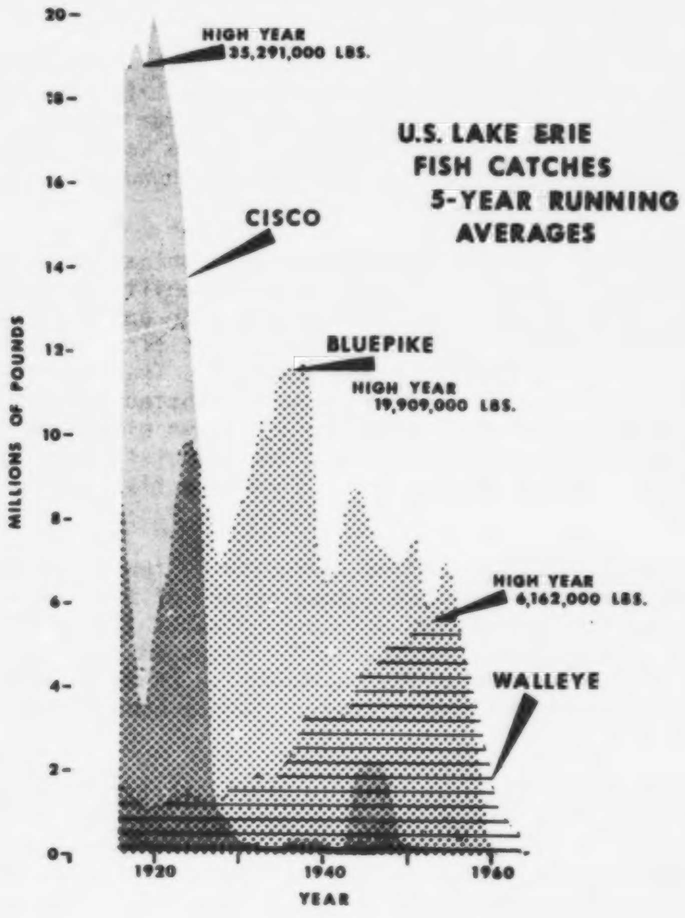

HIGH YEAR
35,291,000 LBS.
U.S. LAKE ERIE
FISH CATCHES
5-YEAR RUNNING
AVERAGES
CISCO
BLUEPIKE
HIGH YEAR
19,909,000 LBS.
HIGH YEAR
6,162,000 LBS.
WALLEYE
MILLIONS OF POUNDS
20
18
16
14
12
10
8
6
4
2
0
1920
1940
1960
YEAR

FIGURE 52

A

TABLE 32

Average combined annual United States and Canadi
production for specified periods of major[1] commercial species of
(thousands of pounds)

Period	Stur-geon	No. Pike	Cisco	Sauger[4]	White-fish	Blue Pike[6]	Wall-eye	Yellow perch	Smelt	Sheeps-head	White bass[5]
1879-1909[3]	1,052	1,356	25,625	3,700	2,402	10,797[7]	--	2,791	--	1,061	611
1910-1919[3]	77	1,250	27,201	3,656	2,945	9,277	1,756	3,017	--	2,499	383
1920-1929[3]	39	77	14,126	2,437	1,675	11,292	1,577	5,356	--	2,367	360
1930-1934	39	62	764	1,943	2,094	14,623	2,113	12,382	--	2,381	447
1935-1939	31	29	1,070	1,414	2,696	18,526	3,515	6,444	--	3,359	655
1940-1944	22	37	283	878	4,058	13,517	3,779	3,869	--	3,624	553
1945-1949	25	21	8,067	567	4,701	12,509	5,807	4,245	--	3,965	701
1950-1954	14	12	475	354	2,297	13,535	7,566	6,784	890	3,492	3,485
1955-1959	14	.14	128	21	749	10,078	10,267	19,540	4,345	4,020	5,092
1960-1964	4	2	8	1	19	3	1,484	20,219	13,508	5,770	4,111
Largest catch	5,187	2,873	48,823	6,181	7,098	26,788	15,405	28,954	11,495	6,566	9,451
Year of Largest catch	1885	1908	1918	1916	1949	1936	1956	1959	1960	1960	1954

1/ Species that have had an annual production greater than 1 million pounds.
2/ Species normally less than 1 million pounds (goldfish, bullheads, burbot).
3/ Average for years of record.
4/ U.S. catch only until 1952.
5/ Includes bullheads through 1951.
6/ Catches of walleye and blue pike combined through 1914.
7/ Probably composed of 8-9 million pounds of blue pike and the remainder walleye.

From "Report on Commercial Fisheries Resources of the Lake Erie Basin," U. S. Bureau of Commercial Fisheries, 1966.

B

TABLE 32

Average combined annual United States and Canadian
for specified periods of major[1] commercial species of Lake Erie
(thousands of pounds)

White-fish	Blue Pike[6]	Wall-eye	Yellow perch	Smelt	Sheeps-head	White bass[3]	Sucker[4]	Channel catfish[5]	Carp	Other[2]	Total Production
2,402	10,797[7]	--	2,791	--	1,061	611	1,350	604	2,480	100	53,923
2,945	9,277	1,756	3,017	--	2,499	383	1,120	1,110	7,544	2,015	63,850
1,675	11,292	1,577	5,356	--	2,367	360	1,090	681	3,189	1,476	45,742
2,094	14,623	2,113	12,382	--	2,381	447	1,462	700	2,659	1,594	43,263
2,696	18,526	3,515	6,444	--	3,359	655	986	641	2,689	1,984	44,013
4,058	13,517	3,779	3,869	--	3,624	553	628	948	2,593	1,744	36,716
4,701	12,509	5,807	4,245	--	3,965	701	506	1,093	2,077	2,226	44,510
2,297	13,535	7,566	6,784	890	3,492	3,485	661	1,589	3,007	873	45,134
749	10,078	10,267	19,540	4,345	4,020	5,092	413	1,770	4,171	733	61,355
19	3	1,484	20,219	13,508	5,770	4,111	333	1,484	4,276	792	52,014
7,098	26,788	15,405	28,954	11,495	6,566	9,451	2,024	2,228	13,419	--	76,313
1949	1936	1956	1959	1960	1960	1954	1930	1917	1914	--	1915

tion greater than 1 million pounds.
pounds (goldfish, bullheads, burbot).

ined through 1914.
ds of blue pike and the remainder walleye.

Resources of the Lake Erie Basin,"
1966.

TABLE 33

U. S. COMMERCIAL FISH CATCH STATISTICS
(Annual Averages in thousands of pounds)

	Cisco	Sau-ger	White-fish	Blue Pike	Wall-eye	Yellow Perch	Smelt	Sheeps-head	White Bass	Suck-er	Cat-fish	Carp	Other	Total	Canada	Total Catch
1955	34	15	375	7,648	5,795	2,408	*	1,614	2,931	256	1,947	3,308	465	26,796	30,285	57,080
1956	59	12	445	6,855	6,130	7,054	*	1,924	2,368	269	1,660	3,425	543	30,744	44,682	75,426
1957	23	7	754	3,981	5,035	8,593	2	3,795	1,424	328	1,554	3,768	442	29,706	37,105	66,811
1958	14	2	177	576	3,961	7,061	1	2,816	942	244	1,472	4,880	429	22,575	30,751	53,326
1959	16	1	46	32	1,168	9,348	15	4,608	818	249	1,429	4,015	238	22,433	31,597	54,030
1960	12	2	15	7	1,171	6,390	28	5,098	1,739	250	1,619	4,572	315	21,258	29,219	50,477
1961	6	*	6	2	805	3,694	16	5,764	2,192	330	1,626	4,698	424	19,563	35,698	55,261
1962	5	*	3	1	433	7,548	74	3,524	1,390	261	1,127	4,764	530	19,660	44,464	64,124
1963	1	*	6	*	800	5,822	306	4,126	1,153	224	1,090	3,338	372	17,238	34,233	51,471
1964	—	*	2.8	*	564	1,519	446	4,549	1,535	239	1,163	2,909	400	13,354	25,381	38,375
1965	1	*	6	*	438	3,157	3	4,086	1,110	1	990	3,191	542	13,525	35,096	48,621
1966[1]	*	*	2	*	163	3,262	8	2,058	1,151	140	710	2,773	248	10,515		

[1] Includes only Ohio catch.

The capability of Lake Erie to support fish, considered as a total population of all species, has apparently been maintained and may be increasing. This means that the habitat is changing in favor of such fish as carp, alewife, shad, sheepshead, etc. These are generally considered as indicators of general water quality degradation.

Massive adult and near-adult fish kills occur in Lake Erie and have occurred on various occasions for many years. These kills are not associated with the decline of desirable species. Species which have been susceptible to kills have commonly been perch, white bass, alewife, smelt, gizzard shad, and carp. Kills seem to be more common in the months of June and August. Occasionally during times of large commercial catches, the appearance of a local kill may be given by the discarding of fish from commercial fishing operations. Sometimes fish kills have been called natural die-off, but this does not appear to be a good explanation. At any rate, it does not appear that massive fish kills have had a measurable effect on any species in Lake Erie.

Doubtless the changing benthic fauna of Lake Erie have had an effect on the fish population because many fish are bottom feeders and prefer certain types for food. It is also true, however, that most fish will adapt themselves, at least up to a point, to the diet at hand. The total effect of changing food supply is not known, but it can be said that the effect has been detrimental to most desirable species and these desirable species are carnivorous types.

Desirable fish species, according to the Bureau of Commercial Fisheries, are experiencing difficulty in reproduction and this difficulty is responsible to a great degree for the decline of these species. The cause appears to be pollutional in silting of spawning areas and depletion of dissolved oxygen.

CHAPTER 5

LAKE ERIE BACTERIOLOGICAL CHARACTERISTICS

WATER BACTERIOLOGY

The U. S. Public Health Service conducted microbiological investigations of Lake Erie and its drainage basin in the spring, summer, and fall of 1963 and 1964 in order to determine present microbiological quality of the waters. Further objectives were to determine points of influx and extent of sewage and fecal contaminated waters and to aid in the evaluation of microbiological water quality criteria for major uses. The following table shows the groups measured and the frequency of measurement.

Groups used	Frequency
1. Total coliform, 35°C	
a. Membrane filter (MF)	all routine samples
b. MPN (most probable number)	selected samples
2. Fecal coliform, 44.5°C	
a. MF	all routine samples
b. E.C. (Escherichia coli.)	10-20% of all samples
c. MPN - E.C.	10% of all samples
3. Fecal streptococci, 35°C	
a. MF (Kenner, etc.)	all routine samples
4. Total bacterial count	
a. MF, 20°C	all lake and inshore samples
b. MF, 35°C	all lake and inshore samples
5. Enteric pathogens	
a. Salmonella, Shigella	Tributary & bathing beach samples
b. Enteroviruses	Tributary & bathing beach samples

All determinations were made in accordance with procedures set forth in Standard Methods for the Examination of Water and Wastewater, 11th Edition, 1960, or in accordance with those established through research at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, and described in Recent Developments in Water Microbiology, 1964.

The coliform group is defined as consisting of aerobic and facultative anaerobic, gram-negative, non-sporeforming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C.

The members of the coliform group are found in the feces of warm-blooded animals, including man; in the guts of cold-blooded animals, in soils, and on many plants. The presence of coliform bacteria derived from warm-blooded animal feces in a body of water is interpreted as indicative of the possibility of the presence of enteric pathogens. Increased densities of coliform bacteria found in water are related to the greater possibility of their association with enteric disease-producing groups found in the gut of ill persons.

The fecal coliform group is that part of the coliform group associated with fecal origin in warm-blooded animals. The purpose of the test is to separate the members of the coliform group into those of fecal and non-fecal origin. The test is based on the ability of coliform bacteria associated with warm-blooded animals to grow at 44.5°C ± 0.5°C and the failure of coliform bacteria from cold-blooded animals, plants, and soil to grow at that temperature.

The sanitary significance of the fecal coliform bacteria in a body of water is described (Public Health Service, 1963) as follows:

> "In untreated waters, the presence of fecal coliforms indicate recent and possibly dangerous pollution. In the absence of fecal coliforms, the presence of intermediate or aerogenes organisms suggests less recent pollution or runoff. Present information indicates that non-fecal subgroups tend to survive longer in water and resist chlorination more than E. coli."

High total coliform densities, accompanied by high fecal coliform densities, indicate the presence of human wastes and the possibility of human enteric pathogens capable of causing enteric infection and/or disease.

The fecal streptococcus group is any species of streptococcus commonly present in significant numbers in the fecal excreta of humans or other warm-blooded animals, rarely occurring in soil or in vegetation not contaminated with sewage. The Public Health Service (1963) states that:

> "The presence of fecal streptococci means that the fecal pollution is present in amounts no greater than originally present or in reduced amounts comparable to the combined effects of natural purification processes, for they do not multiply in water to produce overgrowths as sometimes occurs with the coliform groups."

Recent research studies (Geldreich et.al., 1964) indicate that when the ratio of fecal coliforms to fecal streptococci exceeds 2:1 the fecal bacteria have originated from domestic sewage, whereas ratios of 1:1 or less are indicative of wastes from warm-blooded animals other than man, such as stockyard and dairy animals.

The total bacterial count was determined after incubation at 35°C ± 0.5 for 24 hours ± 2 hours, and at 20°C ± 0.5 for 48 hours ± 3 hours. The method was used to determine an approximation of all viable bacterial populations able to produce colonies under the test procedures. The tests were used to provide information applicable to water quality evaluation and to give support to the significance of coliform test results.

Enteric pathogens were detected according to methods described by Edwards and Ewing (1962). The resulting data were used to demonstrate the existence of enteric pathogenic bacteria such as *Salmonella* and *Shigella* in streams draining into the Lake Erie basin. The data were correlated with associated bacteriological data.

The presence of enteric pathogenic bacteria in a body of water indicates a potential health hazard.

Enterovirus studies were conducted by Dr. Norman Clark, of the Robert A. Taft Sanitary Engineering Center. Enteroviruses such as infectious hepatitis, polio, coxsackie, and echo viruses and adenoviruses may be found in large quantities in the feces of infected individuals, and in sewage. Infections with these agents are widespread in the normal population especially during the summer and early fall. Presence of these viruses in a body of water is indicative of the presence of fecal matter containing them.

WESTERN BASIN

Bacterial water quality in western Lake Erie in offshore waters was measured in 308 samples collected in 1963 and 1964 from the fixed depths of surface, 5, 10, and 20 meters, depth permitting. In order to achieve a more valid picture of bacterial distribution, it was necessary to separate the values according to "surface" and "lowermost" conditions. Samples collected from mid-depth and deep waters revealed a substantial reduction in bacterial densities from those of the surface, and this was true in all three lake basins. A consistent and significant increase in bacterial densities at all depths was found at the inflow areas of major tributaries.

Median total coliform densities for surface and lowermost samples are shown in Figure 53 and Figure 54, respectively. Surface coliform concentrations are expressed in six ranges: less than 1, 1 to 10, 10 to 100, 100 to 500, 500 to 1,000, and 1,000 to 2,400 organisms per 100 ml of sample. Lowermost coliform values include just the first five ranges.

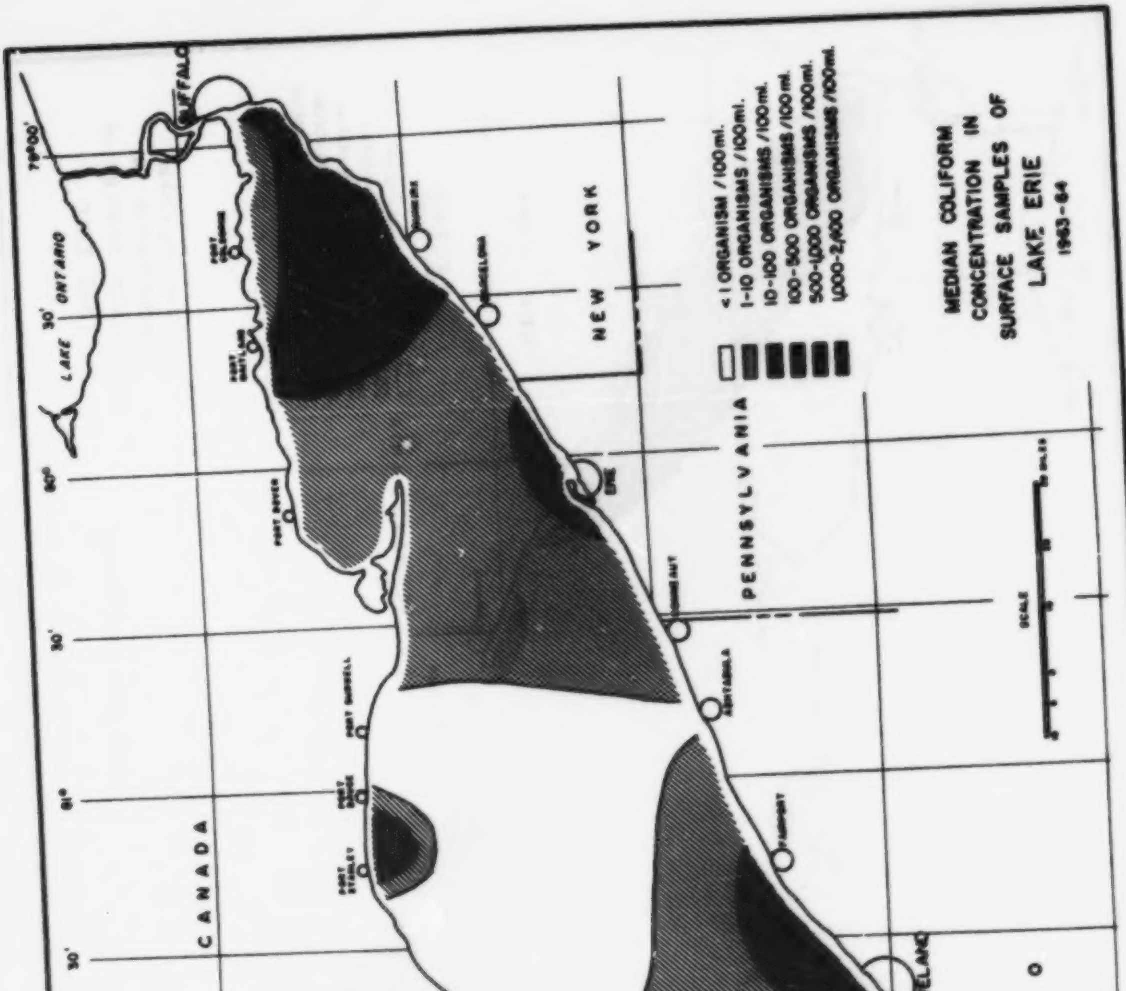
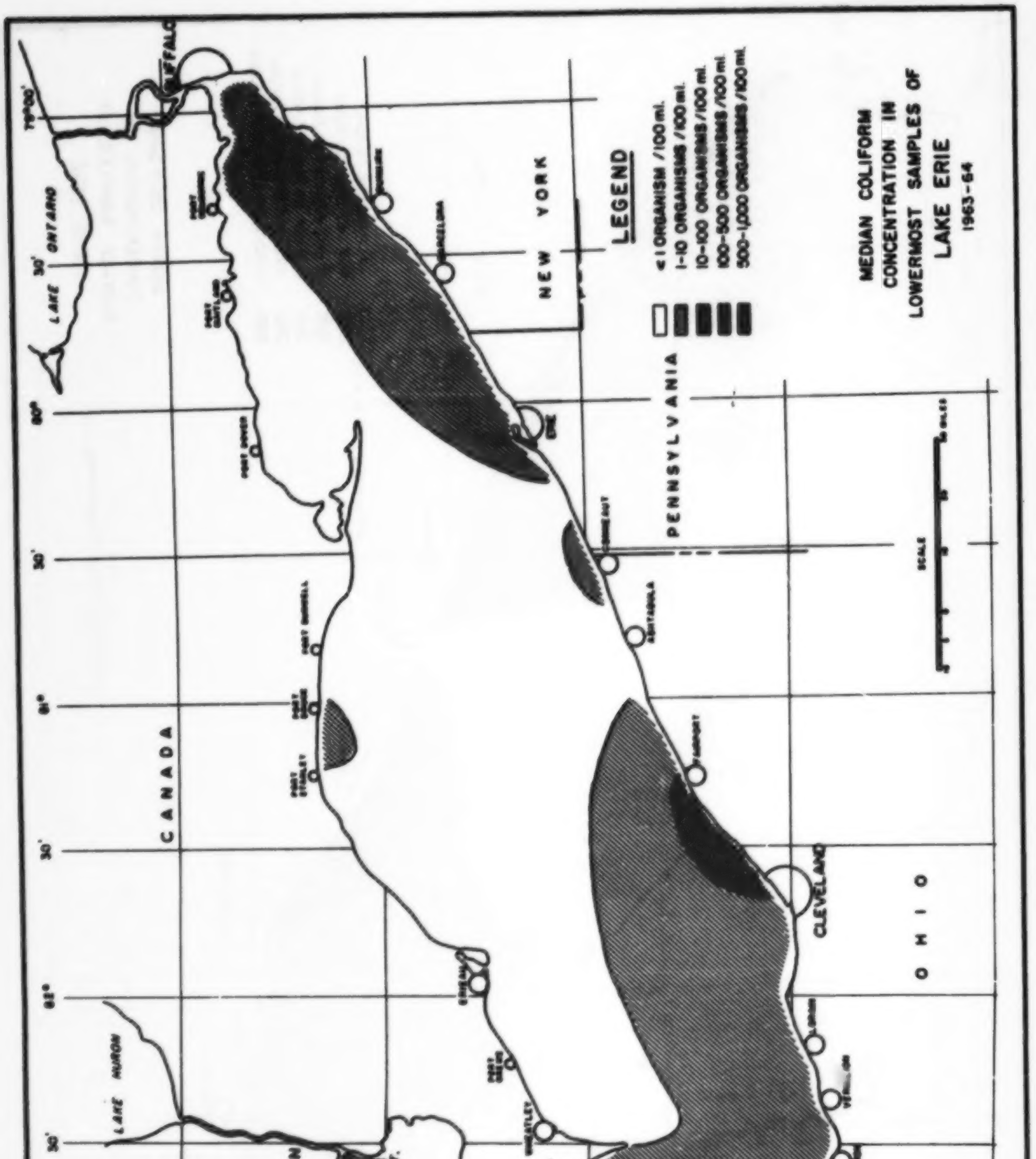

MEDIAN COLIFORM CONCENTRATION IN SURFACE SAMPLES OF LAKE ERIE 1963-64
<1 ORGANISM /100ml.
1-10 ORGANISMS /100ml.
10-100 ORGANISMS /100ml.
100-500 ORGANISMS /100ml.
500-1,000 ORGANISMS /100ml.
1,000-2,400 ORGANISMS /100ml.
LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
CANADA
MICHIGAN
NEW YORK
PENNSYLVANIA
OHIO
BUFFALO
DUNKIRK
BARCELONA
ERIE
CONNEAUT
ASHTABULA
FAIRPORT
CLEVELAND
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
TOLEDO
MONROE
DETROIT
KINGSVILLE
LEAMINGTON
WHEATLEY
RONDEAU
PORT STANLEY
PORT BRUCE
PORT BURWELL
PORT DOVER
PORT MAITLAND
PORT COLBORNE
SCALE
N
79°00'
30'
80°
30'
81°
30'
82°
30'
83°
83°30'
43°00'
30'
42°
30'
41°

FIGURE 53


MEDIAN COLIFORM
CONCENTRATION IN
LOWERMOST SAMPLES OF
LAKE ERIE
1963-64
LEGEND
< 1 ORGANISM /100 ml.
1-10 ORGANISMS /100 ml.
10-100 ORGANISMS /100 ml.
100-500 ORGANISMS /100 ml.
500-1,000 ORGANISMS /100 ml.
LAKE ONTARIO
LAKE HURON
LAKE ST. CLAIR
CANADA
MICHIGAN
NEW YORK
PENNSYLVANIA
OHIO
BUFFALO
ERIE
CLEVELAND
DETROIT
TOLEDO
BARCELONA
DUNKIRK
CONNEAUT
ASHTABULA
FAIRPORT
LORAIN
VERMILION
HURON
SANDUSKY
PORT CLINTON
MONROE
AMHERSTBURG
LEAMINGTON
KINGSVILLE
WHEATLEY
ERIEAU
PORT STANLEY
PORT BURWELL
PORT DOVER
PORT COLBORNE
SCALE
MILES
N
83°30'
83°
30'
82°
81°
80°
79°00'
43°00'
42°
41°

152

FIGURE 54

It is evident that extensive bacterial pollution exists at the mouth of the Detroit River. Off the mouth, median coliform values of 1,000 to 2,400 organisms per ml were found in the surface samples and 500 to 1,000 per ml in the lowermost samples. Fecal coliform densities ranged from 18 to 54 percent of the total coliforms. Numbers of fecal streptococci were less than either fecal or total coliforms. The ratio of fecal coliform to fecal streptococcus exceeded 2:1 at all depths, indicating the presence of human wastes derived from domestic sewage. Total bacterial counts near the Detroit River mouth exceeded 20,000 per ml in the maximum values, indicating the presence of a large amount of organic matter.

From this zone southward to east of Stony Point, Michigan, both surface and subsurface samples showed median total coliform concentrations between 500 and 1,000 organisms per 100 ml, exceeding this range in maximum values. Fecal streptococci densities were below 20 organisms per 100 ml. The ratio of fecal coliform to fecal streptococcus averaged 16:1, indicating the presence of domestic sewage. Total bacterial densities at 20°C and 35°C ranged from 2,700 to 59,000 organisms per ml, with slightly higher values at 20°C.

A zone of median coliform densities of 100 to 500 per ml with three to six percent fecal coliform, along the west shore, was shown only in the lowermost samples, with surface samples showing median counts of less than 100 per 100 ml. It appeared that the Raisin River was supplying polluted water. Similar total coliform densities were found in waters north of Pelee Island with five to ten percent fecal coliform. Fecal streptococci showed a median of 32 organisms per 100 ml. The ratio of fecal coliform to fecal streptococcus did not exceed 2:1, indicating a source from warm-blooded animals other than man.

A zone of median coliform densities of 10 to 100 per 100 ml in surface samples radiated south, southwest, and southeast from the Detroit River mouth area, extending into the southern island group and to the Canadian shore in the Pigeon Bay area. Lowermost samples were similar in area but slightly different in zonal shape. Other areas showed a median total coliform range of 1 to 10 organisms per 100 ml. Fecal streptococci median values were less than 20 organisms per 100 ml in areas with less than 100 coliforms per 100 ml.

CENTRAL BASIN

Total coliforms, fecal coliforms, fecal streptococci, and total bacterial counts at 20°C and 35°C were made on 1,228 samples from central Lake Erie. Samples were taken at the surface and at 5, 10, 20, 30, 40, and 50 meters, depth permitting. Samples taken at mid-depth and below are referred to as "lowermost" samples.

Samples collected from surface waters showed higher bacterial densities than the lowermost samples except for an area around the mouth of the Chagrin River (see Figures 53 and 54).

The highest median total coliform values in the central basin, 100 to 500 organisms per 100 ml, were shown in deep water samples in the offshore area near the Chagrin River. Maximum values reached 3,000 organisms per 100 ml. Fecal coliforms ranged from 4 to 14 percent of the total coliform densities. The ratio of fecal coliforms to fecal streptococci ranged from 6:1 to 15:1, indicating pollution by domestic sewage.

Median total coliform values of 10 to 100 organisms per 100 ml were found in surface samples from two offshore areas. One area was around Cleveland, extending approximately 20 miles north and 30 miles northeast (Figure 53). Maximum coliform values for this area exceeded 5,000 organisms per 100 ml. Median total coliform densities in lowermost samples (Figure 54) ranged from 10 to 100 per ml, but did not exceed 5,000 per 100 ml. Median fecal coliform densities ranged from 4 to 70 percent of the total, indicating the presence of pollution from domestic sources. Fecal streptococcus densities exceeded 20 organisms per 100 ml in the maximum values. The ratio of fecal coliforms to fecal streptococci was 2:1 or greater at all depths, indicating the presence of human wastes derived from domestic sewage. Total bacterial counts in this area at 20° and 35°C at all depths ranged from 91 to 740 per ml in median values and from 570 to 73,000 per ml in maximum values. The pollution effect of the Cuyahoga River was evident. The gross pollution from the Cleveland area was apparently kept close to the United States shore and followed the shoreline east of Cleveland.

The second area of median total coliform densities of 10 to 100 organisms per 100 ml was located along the Canadian shore near Port Stanley and was shown in surface waters only (Figure 53).

Median total coliform values of 1 to 10 organisms per 100 ml were found in a major portion of Central Lake Erie offshore surface and lowermost waters as shown in Figures 53 and 54. Maximum coliform densities were below 1,000 organisms per 100 ml. The ratio of fecal coliform to fecal streptococcus was 1:1 or less. Total bacterial counts at 20° and 35°C ranged from 5 to 110 per ml in median values at all depths.

EASTERN BASIN

Bacterial values were also measured in 255 samples of eastern basin water. As in the other basins, the lowermost samples showed lesser densities than surface samples.

An area of median total coliform densities of 10 to 100 organisms per 100 ml in surface samples was located around Presque Isle, Pennsylvania. Maximum values were 3,400 coliforms per 100 ml, fecal coliforms of 44 percent, and fecal streptococcus of 1,200 organisms per 100 ml. In general, the coliform population from the Presque Isle area was diffused in a fan-like pattern and dissipated in a distance of approximately five miles from the shore. High coliform densities in maximum values accompanied by high fecal coliform values were indications of domestic sewage pollution.

Another major zone with median total coliform values in the surface samples of 10 to 100 organisms per 100 ml extended over most of the eastern half of the basin (Figure 53). The lowermost samples had a median range of 1 to 10 coliform bacteria per 100 ml decreasing to less than 1 north of the international boundary (Figure 54). Median fecal coliform and fecal streptococcus values ranged from less than 1 to 12 organisms per 100 ml. Total bacterial counts ranged from 60 to 420 at 20°C and from 10 to 50 per ml at 35°C in median values.

LAKE ERIE HARBORS (SOUTH SHORE)

Evaluation of the quality of these waters was made in 1964 from the examination of water samples collected from representative sampling points at surface and mid-depth levels. Bacterial pollution was measured in terms of total coliforms, fecal coliforms, fecal streptococci, and enteric pathogens.

Gross bacterial pollution was demonstrated at the mouths of Ottawa, Maumee, Portage, Black, Rocky, Cuyahoga, Chagrin, Grand, Ashtabula, and Buffalo Rivers.

OTTAWA RIVER AND MAUMEE RIVER

A median total coliform value of 90,000 organisms per 100 ml was observed in the Ottawa River which empties into Maumee Bay. The mouth of the Maumee River contained a median of 190,000 coliform organisms per 100 ml. High median fecal coliform (125,000/100 ml) and fecal streptococcus (1,000/100 ml) densities were accompanied by enteric pathogenic bacteria. Six species of Salmonella were isolated in the Ottawa and Maumee Rivers. The peak incidence of Salmonella occurred from January through April 1964.

Bacterial pollution in the Toledo Harbor became well diluted within 2 to 4 miles lakeward of the mouth where median coliform values ranged from 100 to 1,000 organisms per 100 ml, with 10 to 50 percent fecal coliforms.

PORTAGE RIVER

Results from Portage River, at its mouth, showed a median coliform level of 17,500 organisms per 100 ml, with 14 percent fecal coliform. The median fecal streptococci count was 1,100 organisms per 100 ml. Salmonella organisms were found during the spring survey.

SANDUSKY HARBOR

Sandusky Harbor median total coliform densities ranged from 800 to 6,000 organisms per 100 ml with correspondingly high fecal coliform results. The median total coliform value of 6,000 organisms per 100 ml with a fecal coliform to fecal streptococcus ratio of 18:1 was demonstrated at a sampling point east of the Sandusky sewage treatment plant. From the tip of Cedar Point lakeward, median total coliform values were less than 1,000 per 100 ml. In the Sandusky River highest bacterial densities were found near the Fremont treatment plant and the presence of Salmonella was revealed.

LORAIN HARBOR-BLACK RIVER

Results from Lorain outer harbor, lakeward of the river mouth showed a median total coliform range of 100 to 9,000 organisms per 100 ml with 16 to 53 percent fecal coliform. Fecal streptococci median values ranged from 19 to 340 organisms per 100 ml. Median total bacterial counts at 20°C and 35°C ranged from 600 to 150,000 organisms per ml. The coliform numbers in the outer harbor correspond to those in the Black River above the Lorain sewage treatment plant.

The median total coliform counts at the mouth of the Black River ranged from 6,900 to 28,000, while maximum values exceeded 2,000,000 organisms per 100 ml. Median fecal coliform densities ranged from 2 to 64 percent of the total, and median fecal streptococci showed values of 200 to 500 organisms per 100 ml. Salmonella organisms were found just above the mouth of the river.

The outflow of the Black River was traced, bacteriologically, into Lake Erie approximately one mile to the north and east. Stations west of the breakwall showed median total coliform values of less than 1,000 organisms per 100 ml.

ROCKY AND CUYAHOGA RIVERS - CLEVELAND HARBOR

Median coliform densities greater than 5,000 organisms per 100 ml were observed at the mouths of Rocky and Cuyahoga Rivers. Maximum coliform densities ranged from 560,000 to 1,200,000 organisms per 100 ml. Fecal coliform population ranged from 8 to 10 percent of the total coliform, and fecal streptococci showed values from 900 to 49,000 organisms per 100 ml. Fourteen Salmonella serotypes were isolated from the mouth of Cuyahoga River and ten from the mouth of Rocky River. These findings are attributed to the gross pollution of human wastes entering these streams. The water leaving Rocky and Cuyahoga Rivers carries bacterial pollution into Lake Erie. Results obtained from sampling points north and east of the Rocky River, approximately one-half mile from the shore, showed median coliform densities in excess of 1,000 organisms per 100 ml, reaching a level of 86,000 in the maximum values. The total coliform results inside and immediately outside of the breakwall in Cleveland Harbor showed median coliform values from 3,300 to 10,000 organisms per 100 ml with 9 to 30 percent fecal coliform. The ratio of fecal coliform to fecal streptococcus ranged from 5:1 to 30:1. Maximum total coliform values showed a level of 520,000 organisms per 100 ml north of the breakwall. The maximum total bacterial counts at 20°C and 35°C inside and outside of the breakwall ranged from 13,000 to 660,000 organisms per ml. These results indicate that the water inside and immediately outside of the breakwall is polluted to the extent that it cannot safely be used for municipal water source, recreational, or for other uses involving body contact. A marked decrease in total coliform and an increase in percentage of fecal coliform organisms in the harbor was noted during the study.

The gross bacterial pollution from these two tributaries is lost within a distance of 2 to 3 miles into the lake (Figure 55). The pollution tends to flow northeast and east of the harbor, becoming diffused and diluted as it moves into the lake. It is apparently forced close to the United States shore and follows the shoreline east of Cleveland.

CHAGRIN RIVER

Median coliform density in the Chagrin River at its mouth showed a level of 7,300 organisms per 100 ml, reaching a maximum of 90,000, with 23 to 50 percent fecal coliform. The ratio of fecal streptococcus ranged from 2:1 to 3:1. Three species of *Salmonella* were isolated from river samples indicating pollution from human wastes.

GRAND RIVER - FAIRPORT HARBOR

The highest bacterial densities in the Grand River were observed 2.3 miles above the mouth. The median total coliform value was 15,000 organisms per 100 ml with 40 percent fecal coliform. The maximum coliform was 340,000 organisms per 100 ml. The median ratio of fecal coliform to fecal streptococcus was 8:1. Two species of *Salmonella* were found at this sampling point and represented the presence of pollution from domestic fecal sources. Median coliform densities of 1,400 organisms per 100 ml with 7 percent fecal coliform were observed just above the river mouth. The maximum total coliform densities reached a level of 8,000 organisms per 100 ml. The median ratio of fecal coliform to fecal streptococcus was 1:1.

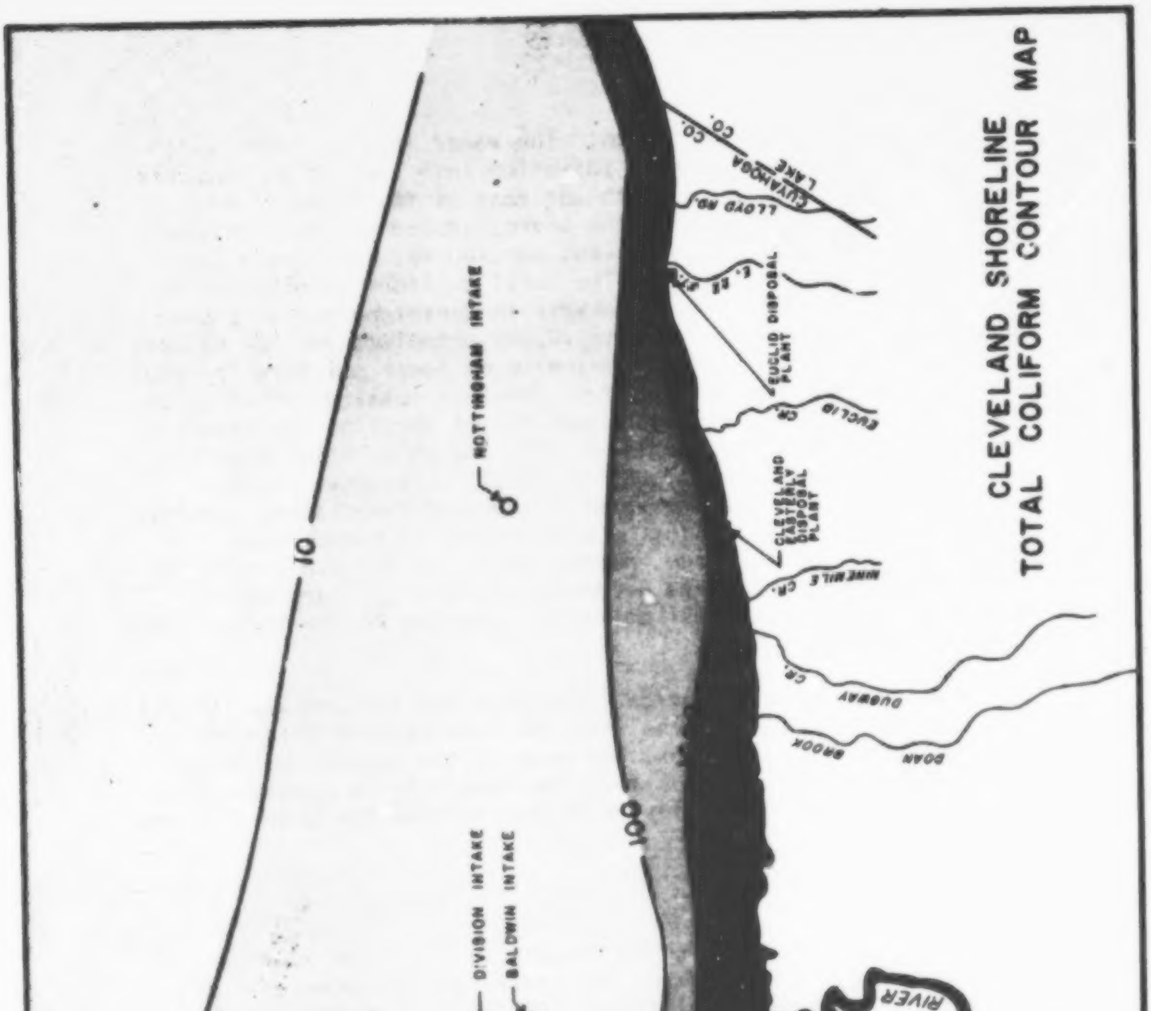

CLEVELAND SHORELINE
TOTAL COLIFORM CONTOUR MAP
10
100
CROWN INTAKE
DIVISION INTAKE
BALDWIN INTAKE
NOTTINGHAM INTAKE
ROCKY RIVER DISPOSAL PLANT
LAKEWOOD DISPOSAL PLANT
ROCKY RIVER
CLEVELAND WESTERLY DISPOSAL PLANT
CUYAHOGA RIVER
DOAN BROOK
DUGWAY CR.
NINEMILE CR.
CLEVELAND EASTERLY DISPOSAL PLANT
EUCLID CR.
EUCLID DISPOSAL PLANT
LLOYD RD.
CUYAHOGA CO.
LAKE CO.
NOTE: BASED ON 1964 DATA-MEDIAN TOTAL COLIFORM CONCENTRATIONS IN ORGANISMS PER 100ml.
SCALE IN MILES
1
0
1
2
3
4

FIGURE 55

In the Fairport Harbor, inside the breakwalls and beyond the river mouth, median total coliform densities ranged from 15 to 540 organisms per 100 ml with 4 to 67 percent fecal coliform. The median fecal streptococci count exceeded the fecal coliform count at one station. A count of 3,200 organisms per 100 ml was observed during the study. These findings indicate pollution from sources other than man. A maximum total coliform density encountered was 34,000 organisms per 100 ml. Median total bacterial counts at 20°C and 35°C ranged from 280 to 6,700 organisms per ml, reaching the highest level of 710,000 organisms per ml.

ASHTABULA RIVER

Median values of total coliform levels in the Ashtabula River at its mouth, and in the Ashtabula Harbor, inside the breakwall, exceeded 1,000 organisms per 100 ml. A range of 17,000 to 64,000 coliform organisms per 100 ml was demonstrated in the maximum values. Median fecal coliform densities ranged from 11 to 28 percent of the total coliform at the mouth of the Ashtabula River and from 6 to 40 percent in the Ashtabula Harbor inside the breakwall. The ratio of fecal coliform to fecal streptococcus was as high as 176:1 in the harbor. Salmonella heidelberg was isolated at a sampling point 0.7 miles upstream. The waters in Ashtabula River, at its mouth, and in the Ashtabula Harbor, inside of the breakwall, were found to be in a continual state of gross pollution in terms of microbiological parameters. Bacterial quality of these waters were unacceptable for recreational purposes and at times for municipal or other uses. Water west of the breakwall was of good bacterial quality. Waters north and northeast of the breakwall showed total coliform densities of 2,700 to 3,300 organisms per 100 ml in the maximum values.

ERIE HARBOR - PRESQUE ISLE

Study of the microbiological results of sampling in the Presque Isle area reveals low coliform densities on the west side of the peninsula near the shore. The results from sampling stations located north and northeast of the isle indicate a substantial increase in coliform densities in the maximum values. A corresponding increase in coliform values was observed in Erie Harbor. Median total coliform values of 2,100 to 17,000 organisms per 100 ml were demonstrated in samples collected from Erie Harbor stations located near Mill Creek and in the ship channel. Maximum total coliform in this area reached a value of 520,000 organisms per 100 ml. Median fecal coliform densities in waters north and east of Presque Isle ranged from 3 to 12 percent of the total coliform densities and fecal streptococci counts averaged from 1 to 10 organisms per 100 ml. The ratio of fecal coliform to fecal streptococci ranged from 2:1 to 5:1 in the median values. The source of this pollution is probably Mill Creek. Salmonella organisms were isolated from 80 percent of the samples collected in both Mill Creek and the harbor. The same organisms were found in Erie's sewage. Generally, the water quality at the stations west of Presque Isle was of satisfactory quality for swimming purposes. The water quality north and east of Presque Isle varied considerably. The maximum total coliform values of 2,800 to 15,000 organisms per 100 ml indicated the pollution entered the lake intermittently, constituting a health hazard in the immediate vicinity along the eastern shore.

BUFFALO RIVER

The Buffalo River showed a median total coliform concentration of 25,000 organisms per 100 ml near its mouth with 14 percent fecal coliform. Salmonella was isolated from this area. The Buffalo River is grossly polluted bacterially.

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